THE IMPACT OF MODULAR DESIGN ON PRODUCT USE AND MAINTENANCE

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THE IMPACT OF MODULAR DESIGN ON PRODUCT USE AND MAINTENANCE

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To Sarah,
with love and appreciation

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NOMENCLATURE

Modularity:

Within product systems, modularity refers to the arrangement of components into subgroups such that each component is independent from components outside its subgroup and such that each component meets common criteria for inclusion within its own subgroup. The arrangement may be hierarchical; a module can consist of smaller modules.

Decomposability Levels:

User-level Decomposable – a product whose modules can be removed and replaced without damaging the module or any other component and requiring only minimal instruction and no additional tools, as part of normal use.

Maintainer-level Decomposable – a product whose modules can be removed and replaced without damaging the module or any other component which may require moderate training, basic tools, or a dedicated work environment such as a workshop.

Manufacturer-level Decomposable – a product whose modules can be removed and replaced without damaging the module or any other component but that requires intensive instruction and training, highly specialized tools, or a dedicated and specialized environment such as a clean room.

Non-decomposable – a product whose modules cannot be removed or replaced once assembled without breaking or damaging other components or prohibiting reassembly.

SUMMARY

Modularity is a means of managing product complexity by arranging components into hierarchical independent subassemblies of common purpose. It offers significant advantages to manufacturers and producers and is assumed to be beneficial for users and owners as well. The producers have received the bulk of the focus, however. Designers must be able to ensure the needs of both parties are being met but too little is currently known about how users respond to modular designs and the designer's role in handling modularity.

This thesis serves as a starting point to correct that deficiency. It demonstrates that modularity has an impact on users and begins the exploration to uncover what that impact might be. The research specifically focused on those aspects of modularity most available to users. The thesis defines terms of decomposability to describe the degree to which users have access to the components in their products. User level decomposability is the easiest of the three to interact with, permitting parts to be removed and replaced by hand with minimal tools or training, and often in direct service of the product's primary function. Maintenance level decomposability permits those typical actions meant to support the primary actions of the product. It may require some tools or training but neither in excess. Other levels of decomposability can require special facilities or years of training. This thesis focused on the modularity exhibited in the first two degrees of decomposability, those within the reach of the typical consumer.

The research itself consisted of three phases: a review of existing literature and previous work, an interview phase and a survey phase. The interview phase served to elicit common terms for discussing the perception of modularity in consumer products. The survey tested the traits that emerged. Both phases made use of object pairs, similar

in purpose but differing in degree of modularity. One variant of each object exhibited user or maintenance level modularity. The other did not.

During the interview phase, participants were shown pictures of eight pairs of objects and asked questions about each variant individually and then to compare the two in terms of use and maintenance. They were then asked to generate a series of word pairs, opposing descriptors that could be used to distinguish between the two variants. These descriptors were reduced to the pairs used most often to describe aspects of use and maintenance. These were then transformed into survey questions.

The survey used the original set of object pairs, less one that did not pass a validation test in the interviews. Each pair was shown on its own page, accompanied by descriptive phrases built around the traits elicited from the interviews. Survey participants were asked to identify which, if any, of the two variants was best described by each phrase and whether that association was weak or strong.

An analysis of the responses indicated that modularity tended to increase users' perceptions of complexity, presence of replaceable parts, and object versatility. It can also be expected to diminish perceptions of durability, ease of maintenance, and ease of use. A closer investigation of object groupings, both predefined and emergent in the data, helped reveal additional context sensitive relationships. Several of the traits also demonstrated strong correlations with each other, useful knowledge for a designer working with modular products.

These results are not surprising, but establishing these relationships is necessary to convert assumptions into knowns before further research can continue. The research in this thesis offers designers useful insight into the relationships of expectations surrounding modular design. As manufacturers continue to push modular design, designers will need to understand its impact on the end users to ensure the needs of all stakeholders are being met.

CHAPTER 1

INTRODUCTION

1.1 Understanding complexity

At least three books have been written about "the last man who knew everything." The books do not agree as to which man this may have been, but they do agree that he lived some time ago. Of the three men so nominated, the most modern died more than a hundred years ago. The authors are implying with the titles of these books that it is no longer possible for one person to be an expert in all subjects, that this has not been possible for at least a century. The extent of human knowledge has progressed too far to be fully explored in a single human lifetime.

It is probably no coincidence that the profession of industrial design emerged just as the last men who knew everything were vanishing. As our knowledge grew ever more extensive so, too, did our capabilities. Our products grew more complex as they took on more features, integrated new materials, and addressed emerging, divergent needs. To manage the increasing complexity, our organizations had to become increasingly complex as well. New roles emerged in the production process, including that of designer.

Even with these divisions, complexity continues to pose significant challenges for designers and manufacturers. One means of managing complexity that gained attention towards the end of the twentieth century is the concept of modular design. A modular design is one that separates components into independent subcomponents or subassemblies. Each subgrouping, if correctly separated from other such groupings, can then be managed as a unit. Modularity then is, in essence, a strategy to divide and conquer complexity.

Complexity management is of significant interest to manufacturers, who must balance a wide variety of conflicting needs and requirements. As a result, the exploration of modularity has largely focused on its utility to makers and producers. The research reflects this, focusing almost exclusively on the production aspect of modular architecture. Any benefits or costs to pursuing a modular architecture are almost always framed relative to the manufacturer, addressing impacts of assembly, inventory, and product families. There is also significant research devoted to achieving modular design, the *how* of modularity but the reason for pursuing modularity design, the *why,* is directly tied, again, to the benefits for the manufacturer only. The third member of the product creation loop, the user, goes almost unmentioned. When benefits to the user are discussed, they are almost always indirect. The improvement the user sees – lower unit cost, an increased product variety, and the potential for customization – emerge only through benefits already experienced by the manufacturer.

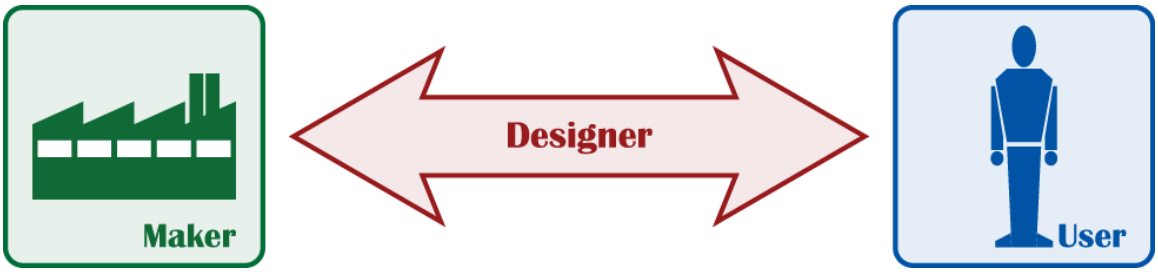

Figure 1. Maker-Designer-User Relationship

The designer is often depicted as the interface between the user and the manufacturer. In this role, the designer serves as the advocate of both, working to ensure that the user's needs are met without exceeding the manufacturer's capabilities. Current research into modularity does not permit the designer to fulfill that responsibility, a deficiency this thesis aims to help correct. The intent is to start a conversation about the

impact of modular design on product use and maintenance, with the aim of offering designers advice on how their decisions in regard to modularity affect users.

Through a two phase comparison of products of varying modularity, this thesis demonstrates that modularity does have an impact on user perceptions. Several general behaviors are identified as well as multiple context specific relationships.

1.2 Thesis Organization

The next chapter defines modularity and the specific focus of this thesis and follows with a presentation of the previous research into the benefits of modular design. It concludes by identifying the specific gaps in the research this thesis is intended to fill and a description of the constraints used to keep such an exploration manageable.

Chapter 3 describes the typologies used to select the objects for comparison and the two phase research approach that followed. The interview process is outlined as well as the survey that built upon the initial discoveries from those interviews.

Chapter 4 presents the data from each phase and describes general trends related to modularity. It also identifies and explores several relationships specific to particular product categories. Chapter 4 concludes with a depiction of several trait relationships within the context of modular design.

Chapter 5 places the findings from Chapter 4 into a design context and proposes new directions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

2.1.1 Definitions

2.1.1.1 The Definition of Modularity

Ulrich and Tung (1991) were among the first researchers to investigate the benefits of using modularity to manage complexity. They described modularity as a relative property depicting how the components of a product were organized. A modular product, in their definition, consists of subgroups of components organized by function and grouped such that interactions with components in other groups were minimized. The opposite of a modular product would thus be an integral product, consisting of components with a high degree of interdependence virtually inseparable from each other.

The work of Tung and Ulrich established the basis for further study of modularity and many future researchers built off of their beginning. They were the first to discuss the potential costs and benefits of modular architecture, to depict common formats to achieve modularity (see Figure 2 and Section 2.1.1.2), and to ask the questions that would propel initial research into the effects of modularity (Ulrich & Tung, 1991).

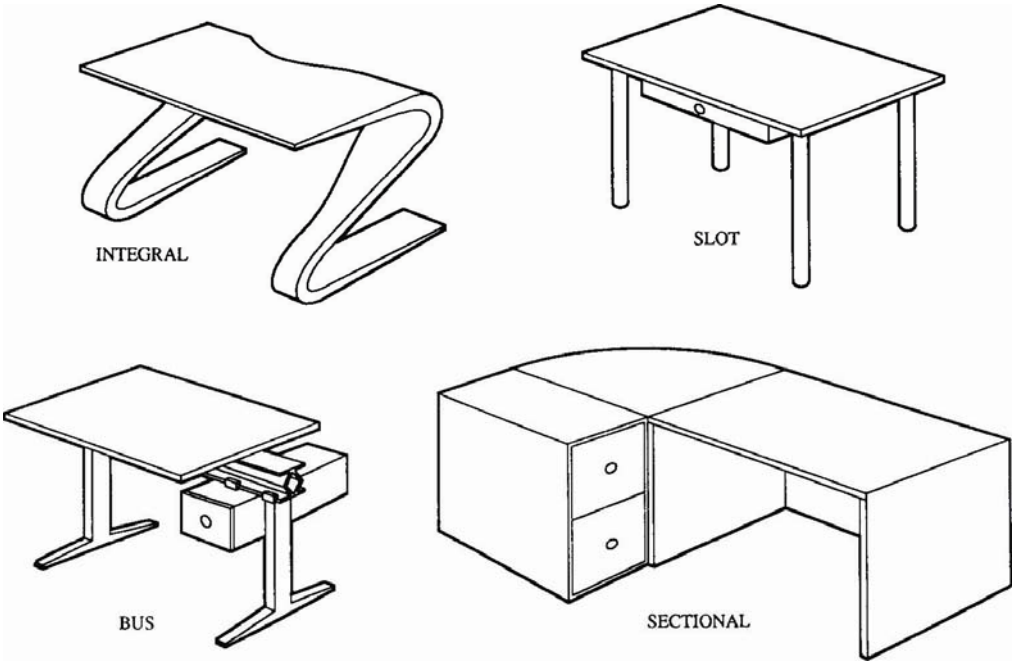

Figure 2. Examples of modular formats as depicted in Ulrich (1995)

Since that initial depiction, research into modularity has blossomed. Modularity is, however, a very general term, widely used and ambiguously defined. Various industries and authors perceive modularity differently. Modularity has been variously described as a one-to-one mapping of function to component (Ulrich, 1995), independence between components driven by standardized interfaces (Sanchez & Mahoney, 1996), a minimization of interactions between components (Kamrani & Salhieh, 2000), and an expression of how difficult it is to separate and recombine product components (Schilling, 2000). More than a decade after Ulrich and Tung first presented their paper, Gershenson, et al. (2003) found it necessary to combine and refine the diverging definitions. They returned to something very similar to what Ulrich and Tung had first identified and their definition will serve as the basis for this exploration:

> There are therefore three fundamental elements to modularity: the independence of a module's components from external components, the similarity of components in a module with respect to their life-cycle

> processes, and the absence of similarities to external components (Gershenson, Prasad, & Zhang, 2003).

Their definition of modularity is independent from function. Gershenson et al relate it to life-cycle processes, in this definition and elsewhere (Gershenson, Prasad, & Allamneni, 1999), but either criterion will serve. As long as the components are grouped for a reason, be it function or life-cycle, then the product exhibits modularity. For purposes of this paper, modularity will be considered as follows:

> Modularity refers to the arrangement of components into subgroups such that each component is independent from components outside its subgroup and meets common criteria for inclusion within its own subgroup. The arrangement may be hierarchical; a single module can consist of multiple smaller modules.

Under this definition a video card in a PC would be considered a module. Its components are independent from the rest of the computer, linking only through the predefined interfaces. The video card can be any formation that fits within the predetermined structure delimited by the size of the casing and the heat restrictions, thus meeting the independence requirement. The various components attached to the video card are assembled expressly for the purpose of managing video calculations, thus meeting the common criteria requirement.

2.1.1.2 The Forms of Modularity

Ulrich and Tung (1991) identified five modularity formats, which Ulrich later reduced to three: slot, sectional, and bus (Ulrich, 1995). In slot architecture, each part has a separate interface that does not permit interchangeability amongst parts. A part can only occupy its defined slot, although there may be multiple available slots for a particular type of part (Ulrich, 1995). In the car, for instance, there are four wheels, but a wheel can only occupy a wheel slot and a seat can only occupy a seat slot. In bus architecture, a central component serves as the base and offers several identical interfaces

for the connecting components. Each connecting component can attach to any of the interfaces in any order (Ulrich, 1995; Ulrich & Tung, 1991). Most computer motherboards have a bus architecture that can accept a mix of video cards, sound cards, network cards, and other devices. In sectional architecture, each component can contain multiple interfaces and functions are added to the whole by connecting one component to the next, in any order (Ulrich, 1995; Ulrich & Tung, 1991). A plumbing system is sectional by nature. Any number of pipes and fixtures can be attached end to end, adding to the overall function of the system. These various formats are not mutually exclusive, however. It is possible to find products that exhibit them in varying degrees, even including all three. A typical consumer Ethernet hub is one such product. The power adaptor attaches through a unique slot but the Ethernet cables attach in a bus configuration; specific order of placement in the available ports is unimportant. The cables themselves are part of a larger sectional system.

2.1.2 Research

Research into the effects of modularity on manufacturers continued even while its definition was under discussion. Modular products require greater initial design effort to establish appropriate interface architecture, but once established, further design and production work can proceed in parallel. Different groups can work on separate modules without worrying about interfering with each other. This aids design, manufacturing, and testing. Testing itself is also easier because the pieces are separate and because the input and output requirements are clearly defined at the start of the process (Fixson, 2007).

Independent modules permit manufacturers to offer greater variety to their customers, and even allow the potential for mass customization, when mass produced modules can be combined in a wide variety of customer-chosen configurations to cheaply produce virtually unique products. Such component sharing can, however, lead to a reduction in perceived value and a loss of distinctiveness. For example, in the

automobile industry, the Infiniti G20, a luxury vehicle, was roundly criticized for using many of the same components as the Nissan Sentra SE, a lower-priced value vehicle (Desai, Kekre, Radhakrishnan, & Srinivasan, 2001). On the other hand, component sharing and modularity in general can offer a number of advantages in inventory management, primarily by spreading risk amongst several products (Fixson, 2007).

At the other end of the product's lifecycle, modularity can also aid in disassembly and disposal. It is modularity that even permits the option for maintenance. A truly integrated product that ceases to function properly can only be patched or replaced, not repaired, no matter which component failure caused the malfunction. The mutual dependencies of the integrated components, by definition, prohibit the replacement of only one. If a product is modular enough, however, it will be possible to remove the offending component and either repair it directly or simply replace it. For example, if the integral table in Figure 2 above were to break a leg, the table could not be repaired to its original state. However, if the modular table leg broke, the leg could be detached and swapped for a new one quickly and easily. Gershenson, as mentioned earlier, is one of many who deliberately equate modular design with lifecycle considerations, seeing it as a means of enabling recycling and reclamation once repair is no longer possible (Gershenson et al., 1999; Gershenson et al., 2003; Newcomb, Bras, & Rosen, 1998).

Separating components into independent modules makes local upgrades easier and permits organizations to specialize. This can lead to modularization of the organization itself. In some cases it will improve knowledge management and lead to a more efficient process as individual modules are subcontracted to firms able to focus their efforts on a single task (Sanchez & Mahoney, 1996). This same trend, however, can lead to stagnation. The specialization that permits individual modules to excel tends to resist adaptation of the architecture itself. With a clearly defined modular architecture, risk is reduced, but little room is left for large-scale innovation (Fleming & Sorenson, 2001). A product that is too modularized can lead to premature fixation, settling firmly

into a suboptimal configuration (Ethiraj & Levinthal, 2004). The splitting of the task among several firms can also eliminate any central control and complicate coordination between the firms, to the detriment of both firms and products (Staudenmayer, Tripsas, & Tucci, 2005).

It is also worth noting that the increased flexibility of a modular product usually comes at a price in efficiency. The accommodations necessary to establish appropriate interfaces between components impose additional performance constraints (Fixson, 2007). When these interfaces are physical they will, at the very least, add mass to the product, but may also slow down performance.

Despite the variety of costs associated with modularity, the benefits to the manufacturing process are significant and the choice is often unconscious. Modularity tends to emerge in products as a natural maturation of technology. Schilling identified eleven factors that can drive a technology toward or away from modularity, including customer demands and perceptions, customer heterogeneity, and market diversity (Schilling, 2000). There are times, however, when modularity is intentional rather than emergent.

Achieving modularity deliberately by design is rarely a simple matter. One approach to capture modularity transforms the concepts of suitability and independence into mathematical matrices. This particular approach, however, starts with an established product and attempts to modularize it (Huang & Kusiak, 1998). Yu, et al. on the other hand, look at the nature of changing customer demands to determine if modularity would be beneficial. This happens before design of a product begins. Their approach depends on the behavior of numbers over time in repeating customer surveys (Yu, Gonzalez-Zugasti, & Otto, 1999). Others suggest function mapping or offer a criteria checklist that should be met before attempting a modular design (Dahmus, Gonzalez-Zugasti, & Otto, 2001; Tsai & Wang, 1999; Tsai, Wang, & Lo, 2003). Asan et al are among the few who offer suggestions on the entire process. They proposed an eight stage process that starts

with an analysis of a firm's existing portfolio and finishes with an evaluation of the resulting design (Asan, Polat, & Serdar, 2004).

2.2 Opportunities and Directions

2.2.1 Gaps in the Research: Where is the user?

Interest in modularity has continued to grow. Manufacturers in particular seek to understand the benefits and tradeoffs modularity provides and this is evident in the research coverage. The existing research investigates modularity from first concept to final sale. It also discusses the impact of modularity on product disposal. What it does not discuss is what happens in between: ownership and use. Little has been said about the maintenance and upkeep potential, and less has been said about direct effects on the user. In a review of sixty papers about modularity, only one mentioned effects on ownership. Tsai et al discuss maintenance needs and ultimately developed a mathematical formula to optimize product modularity for maintenance purposes (Tsai et al., 2003). No other paper found in this search mentioned user experience.

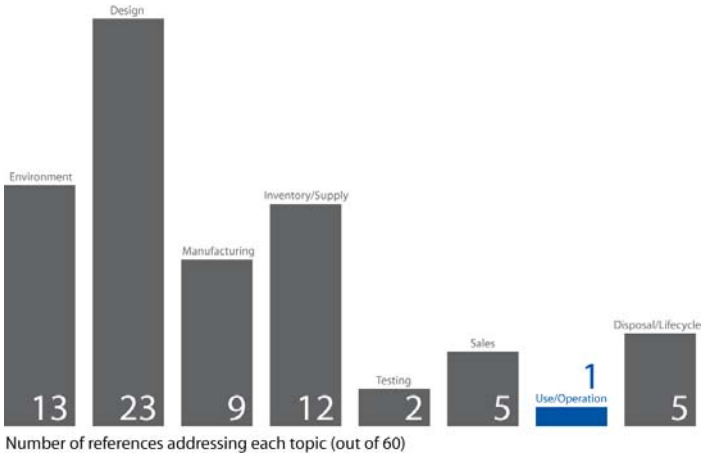

Figure 3. Graph of modularity research coverage in relation to product lifecycle

It may be that the problem of user experience with regards to modularity has not been studied because there is no perceived problem, nothing to study. However, it is not mentioned in the literature found thus far.

This is a topic designers cannot ignore. Since Henry Dreyfuss first wrote Designing for People, the user has been a primary focus for industrial designers (Dreyfuss, 1955). Entire fields of study such as human factors, ergonomics, and universal design are all intent on ensuring that the users are well-served by the products they own.

The lack of consideration for the user is a gap in the modularity research that this thesis is intended to address. It is, however, a broad gap with much to cover. This thesis will focus on a specific area - how modularity affects the perception of the ownership in terms of use and maintenance. More specifically, this thesis addresses the following questions:

1. *What are the effects of a perceptible (i.e. evident) modular architecture on the experiences of the user and the maintainer?*
2. *What rules can designers follow to influence these experiences?*

2.2.2 Further Refining Focus: Decomposability

Under the definition arrived at in the literature, a product can only be identified as "more or less modular" than another product; it cannot stand by itself as some measure of "modular." The definition is relative rather than categorical. Thus, to work with the concept for research purposes, it becomes necessary to add another criterion to limit the scope. In this case, as this thesis will be focusing on the user and the maintainer, it would be useful to limit modularity under investigation to that which is perceptible to user and maintainer. As Gershenson et al found, and what prompted their initial efforts to collate the diverging definitions, there is little consensus among observers – professional, academic, or novice – as to what products are "modular" (Gershenson et al., 2003).

Given then both the generality of the term and the inconsistency in its application, rather than query users on their experience of modular products, this thesis will rely on a functional description of modularity. More specifically, this thesis is interested in those products whose modularity permits disassembly or part swapping, products that are decomposable. The term "decomposability" is broken into four categories based on the level of effort required to effect the decomposition.

User-level Decomposable – a product whose modules can be removed and replaced without damaging the module or any other component and requiring only minimal instruction and no additional tools.

A product that is user-level decomposable is intended to allow component disassembly or swapping during normal use. The beaters in an electronic mixer, the rechargeable battery in a cordless drill, and the magazine in a handgun are all user-level decomposable components. Changing any of those components out for another, either for replacement, upgrade, or replenishment is considered typical use of the product.

Maintainer-level Decomposable – a product whose modules can be removed and replaced without damaging the module or any other component, but which may require moderate training, basic tools, or a dedicated work environment such as a workshop.

A maintainer-level decomposable component is meant to be accessed only during support actions such as minor repairs or upgrades. Disassembling and replacing the blade on a band saw, rotating the tires on a car, or replacing the soundcard in a PC are all maintenance level decomposition actions. Note that it is possible for a user to perform the maintenance level actions. They are not restricted to designated maintenance personnel, but these actions take place in a context outside typical operational use.

Manufacturer-level Decomposable – a product whose modules can be removed and replaced without damaging the module or any other component, but that requires intensive instruction and training, highly specialized tools, or a dedicated and specialized environment such as a clean room.

Manufacturer level decomposition occurs during refurbishing or operations requiring complex machinery or support on an industrial scale. Refurbished video-game consoles and laptops that must be sent to the maker for repairs are two examples of manufacturer level decomposable products.

Non-decomposable – a product whose modules cannot be removed or replaced once assembled without breaking or damaging other components or prohibiting reassembly

It is possible for a company to assemble a modular product in such a fashion that it could not then be disassembled. Such modularity would be invisible to the user, rendering the product no different in its appearance from an integral product. This is also effectively the case for products that are only decomposable on a manufacturer level. The modularity of such products may have a detectable influence on the user experience, but those interactions are beyond the scope of this thesis. This thesis is instead focused on modularity whose properties are immediately accessible to and perceivable by the user – modularity that is decomposable at the user and maintainer level.

CHAPTER 3

METHODOLOGY

3.1 Modularity Typologies

The preliminary research for this thesis consisted of an exploration of a pair of product typologies in order to understand relationships between product scale and modularity format. The first typology placed a series of modular products on a continuum of size, defined in relation to the human body with five categories:

- **Fingers** – Objects primarily manipulated by fingers such as coins, pencils, or hearing aids.
- **Hand** – Objects primarily manipulated by a single hand, although a second hand may sometimes be used. Examples include cell phones, hammers, or coffee mugs.
- **Shoulder** – Objects too large to be held in a single hand, but not yet the size of the human body. These objects are usually manipulated using both hands, but not all, of the body. Examples include hockey sticks, suitcases, or shopping carts.
- **Body** – Objects as large as or capable of covering or containing the human body. Examples include desks, washing machines, or riding lawnmowers.
- **Environment** – Objects that permit nearly free movement for a human body within their volume were that volume empty. Examples include cubicles, cargo containers, and airplanes.

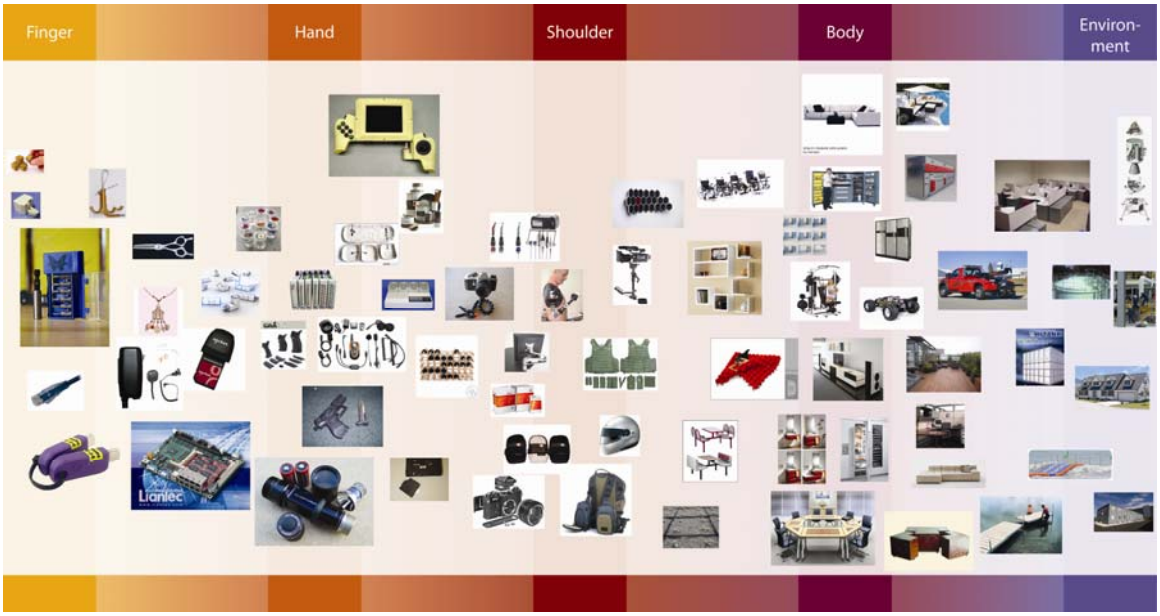

Figure 4. Size Typology

The second typology employed a trinodal scale based on the modularity format proposed by Ullrich (1995) as discussed in section 2.1.1.2: slot modularity, bus modularity, and sectional modularity. Object images were arranged by how strongly each form of modularity was represented within the object. Purely sectional objects were placed close to the sectional node, whereas objects with degrees of all three formats were placed equidistant from each node, near the center of the graph. See Figure 5 for an image of the format typology. Larger versions of both typologies can be found in Appendix A.

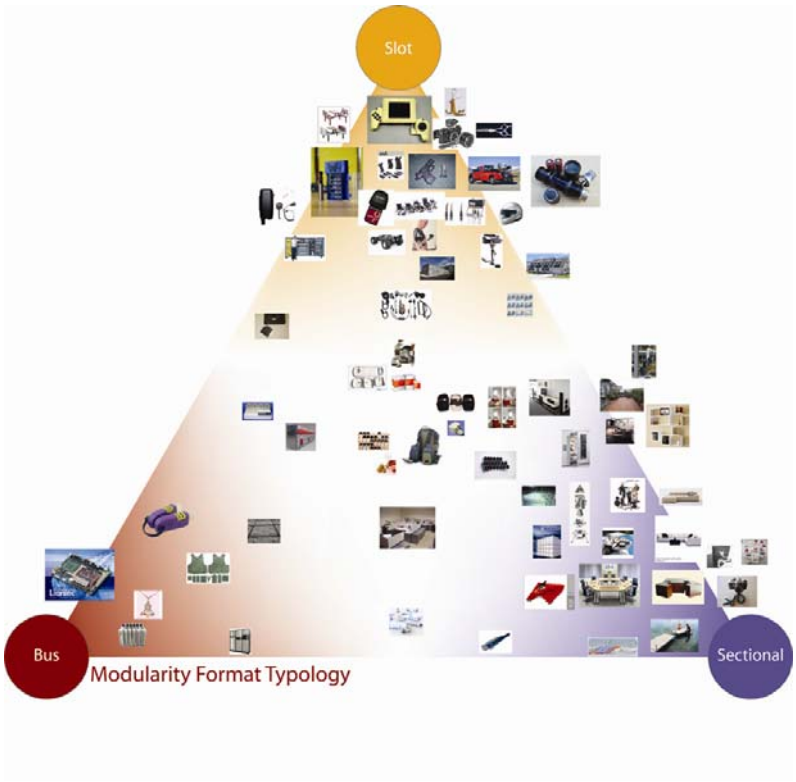

Figure 5. Modularity Format Typology

The object images used in the typology were collected through an internet-based keyword image search using Google Image Search. Keyword combinations included the term "modular" and a term representing each category descriptor (e.g. "modular hand" or "modular sectional"). The gathered product images were plotted on a nodal graph. It was observed that a combination of formats was more common than strict adherence to a single format. Bus modularity appears to be the rarest of the three formats.

Once these typologies were complete, they were then combined. Each object was assigned a color value based on its placement within the chart, and that color was plotted over the opposing chart (Figure 6 and Figure 7). Considering the two charts, it became apparent that the potential for sectional modularity grows and bus modularity diminishes in prevalence as the product grows in scale, but the mixed and slot approaches are present at all scales.

Figure 6. Mixed Typology: Format plotted to Size

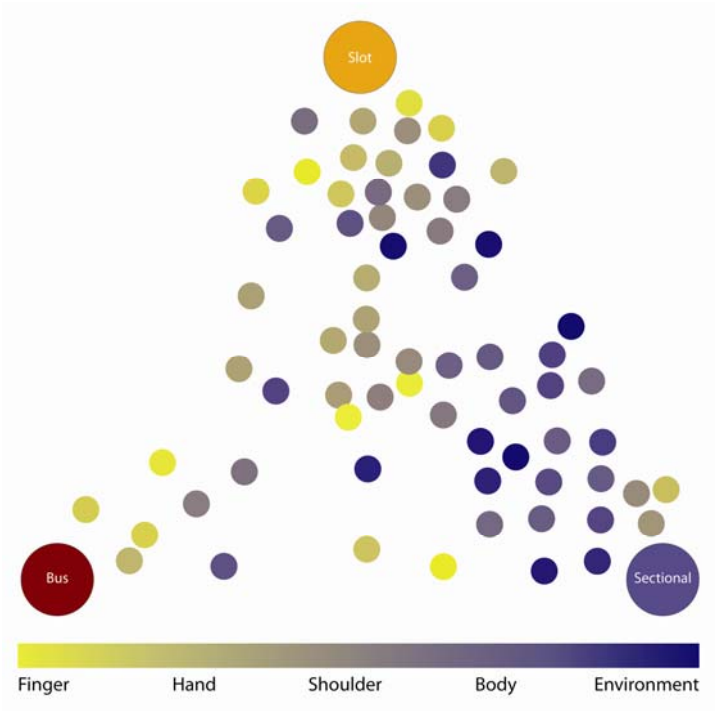

Figure 7. Mixed Typology: Size plotted to Format

3.2 Experiment Design

The aim of the research was to study the impact of modular design on product use and maintenance by examining the impressions and expectations of adult consumers. The primary research was broken into two phases:

Exploratory interview phase: The purpose of this phase was to generate a user-driven vocabulary to describe the perceived impacts of modularity. Interview participants were asked about their impressions of pairs of related items whose primary difference is their relative modularity. The most common descriptors participants assigned to the modular objects were then culled from the interview responses and used as the basis of the next phase.

Survey phase: This phase validated and expanded upon the results of the interview phase. A new pool of respondents reviewed the traits identified in the interviews and identified which of two objects each phrase best described. The larger respondent pool and the survey format enabled the relationships established by the interview phase to be quantified and examined in greater detail.

3.3 Object Selection

Both phases of the research asked participants to compare images of paired objects. There were nine pairs total and each pair represented a different general product type, from cameras to cubicles. The objects in each pair were chosen to represent a wide degree of user and maintainer level decomposable modularity. Modularity is a relative concept and virtually all objects are modular to some degree, even if only at the atomic level. The objects for this research were chosen for their perceivable differences; in most cases both objects could technically be considered modular. For clarity, the more modular object will be referred to simply as the modular variant and the less modular object will be referred to as the non-modular variant.

For the modular object in the pair, objects were selected whose components arranged into independent, and often nested, subgroups that could be accessed and disassembled with minimal tools. Object images were carefully chosen according to the established definitions of modularity such that their modular characteristics would be perceivable to the participants. Furthermore, it was important that subjects be able to understand the characteristics of the specific object's modularity, but it was not necessary that they be able to label the object as modular or non-modular.

Figure 8. Object pair example: Cameras

The object categories were chosen using the results of the typology to achieve a mixture of sizes and formats. Finding non-modular variants distinct enough to oppose the modular variants from the typologies was not always possible, so pencils and mops, which were not part of the original typology mapping, were added. Both were chosen for their relatively simple function and their diverse but familiar forms. The chosen mop variants were a sponge mop and a sheet mop, here represented by the Swiffer[tm] brand. The pencil is prevalent in both solid wooden variants and mechanical variants consisting

of several parts. The pencil also served as a finger-scale object, as none of the objects pulled from the typology came from the finger category.

In several cases, the original images found through the Google Image search were not of high enough quality for the anticipated use. These images were replaced with high quality images of similar products, although in the case of the weights the home gym set was transformed into a set of hand weights for clarity of comparison. The final object pair categories used in the interviews were cameras, chairs, desks, flashlights, mops, offices, pencils, and weights. The relevant images can be found in Appendix B2.

3.4 Interview

3.4.1 Conducting the Interview

Interviews were conducted with 5 adults chosen from a convenience population of local professionals and students. The interviews occurred one on one and were digitally recorded. Participants were told that they would be asked questions about consumer products and that they should provide answers that correspond to their own beliefs. No briefing on modularity was given. The participants were ensured by the interviewer that they would not be judged according to their answers, that there were no correct or incorrect answers, and that their answers would be kept confidential. The participants were presented with pairs of images of associated products similar to Figure 8. The specific questions are discussed in Section 3.4.2 below. If participants needed to have a question clarified, the interviewer tried to rephrase the question. However the interviewer did not provide an answer to a question that might influence the participants' future responses. At the conclusion of the interview, participants were debriefed and thanked.

3.4.2 Interview Questions

The interviewees were shown images of one of the predetermined object pairs and asked several questions about the individual products displayed, broken into four phases:

1. **Context:** to establish whether the volunteer had ever owned the object, what they believed its purpose to be, where it might be used, and how it would be maintained and operated. This was done for each object in the pair to establish the participant's experience with the objects.
2. **Comparison:** why participants thought someone might choose one object or the other. Participants were also asked how easy they thought each object would be to use and maintain.
3. **Descriptors:** To generate lists of opposites that could be used to distinguish the two objects. Participants were free to name as many opposites as they wished. They were then asked which of the opposite-pairs was the most relevant to the use of the displayed objects, and which set of terms was most relevant to the maintenance of the objects.
4. **Modularity** *(not begun until the interviewee had completed the first three stages with each pair of objects)*: To establish if participants felt either product demonstrated more modularity than the other, using the definition of modularity established earlier in this paper. If participants identified one of the objects as more modular, they were asked to describe what features of the object led them to that conclusion. This section of the interview was included to help validate the object selection.

See Appendix B1 for the full list of interview prompt questions.

3.4.3 Eliciting Traits for Questionnaire Construction

After the interviews were complete, the audio recordings were transcribed. The word descriptors from the third phase were grouped by meaning and additional descriptors were pulled from the earlier questioning portion. Collecting the words as opposing pairs during the interview contextualized the individual terms and minimized ambiguity in the case of words with multiple possible meanings. The descriptors were sorted by meaning and each group was assigned a label. For example, Table 1 below shows all the participant descriptor pair responses including duplicates that have been grouped together under the "Complexity" category.

Table 1. Subject-created descriptor category example

Category: Complexity *(Complex/Simple)*	
Modular Phrase	**Non-modular Phrase**
mechanical	non-mechanical
more involved	less involved
automatic	manual
complex	simple
complex	simple
technologically advanced	untechnologically advanced
not simple	simple
complex	simple
complex	simple
complex	easy
complicated	easy
complicated	easy

The grouped sets were then assigned values for the size of the set as a measure for how often that particular concept was brought up in the interviews. They were also assigned values for how consistently the opposing descriptors were applied to the modular variant in the object pair. In Table 1, the consistency is 100% since "complex,"

or an analogous term, was always applied to the modular object. Finally, the category was scored for how often a member of the set was identified as important for use or maintenance. See Table 2 for the list of categories and their scores.

The trait sets were then restricted to those that appeared most often, favored one response for the modular object over the other, and received at least one vote for importance to maintenance and at least one vote for important to use. This left eleven categories, highlighted in green in Table 2.

Table 2. Category response counts

Category Title	Responses Included	Most Popular Descriptor	Consistency of Application	Count of Votes for	
				Use Significance	Maintenance Significance
Coldness	7	Cold	100%	0	0
Comfort	4	Comfortable	100%	2	0
Complexity	12	Complex	100%	8	8
Control	3	Limited Control	67%	3	0
Cost	8	Costly	50%	0	2
Difficulty	8	Difficult	50%	6	4
Disassembly/Replacement	6	Replaceable	100%	4	4
Durability	5	Not Durable	80%	1	2
Form/Function Emphasis	8	Focus on Function	100%	2	2
Functionality	5	High Quality	100%	3	1
Material	5	Synthetic	100%	0	1
Newness	12	New	92%	0	2
Openness	4	Open	50%	1	0
Parts	8	Many	100%	0	6
Permanence	14	Long Lasting	64%	3	9
Portability/mobility	3	Mobile	67%	2	1
Professional Level	9	Expert/Professional	67%	2	1
Seriousness	6	Serious	83%	3	0
Size	9	Large	78%	2	1
Status Visibility	2	Hidden Status	100%	2	0
Sustainability	3	Sustainable	67%	1	1
Use Intensity	6	Intense	50%	4	3
Versatility	11	Versatile	100%	9	6

"Size" was grouped with "portability" keeping the latter term as one that relied on perception rather than direct measurements. "Sustainability" was eliminated at the judgment of the researcher for its weakness in all three scores of consideration. The categories were then transformed into trait descriptions to be used in the follow-on survey. Descriptions for ease of use and ease of maintenance were also added, bringing the total number of traits back to eleven (see Table 3).

Table 3. Interview categories converted to survey phrases

Category	**Survey Phrase**
From Interview	
Complexity	This product is more complex
Disassembly/Replacement	Parts of this product can be replaced
Durability	This product is more durable
Form/Function Emphasis	This product emphasizes function over form
Functionality	This product will perform better
Permanence	This product will last longer
Portability/mobility	This product is more portable
Professional Level	This product would be used by a professional
Versatility	This product is more versatile or adaptable
Added by Researcher	
Ease of Maintenance	This product is easier to maintain
Ease of Use	This product is easier to use

3.5 Questionnaire

3.5.1 The Survey Tool

Questionnaires were sent to a convenience sample of approximately ninety adults recruited through email and word of mouth. The questionnaires were delivered via email and responses were collected in the same fashion. The email served as a cover letter and the questionnaire was attached as a separate document.

The body of the email introduced the purpose of the study as an effort to "investigate the impact of product design differences on people's experience using and maintaining the product." Participants were informed that their participation would help in the understanding of product design and aid in the design of future products and were told to expect the questionnaire to take fifteen to twenty minutes to complete.

The first page of the questionnaire provided instructions. Each following page focused on a different object pair from the set of eight that passed the interviews. The desk images had already been discarded from the set; the interview participants consistently found the desks to be identical in modularity.

At the top of the object comparison pages two objects were shown, one to the left of the page and one to the right, as in the example page depicted in Figure 8. The arrangement of modular and non-modular variants was randomized to ensure that the more modular products did not always appear on the same side of the page. Participants were asked to identify the purpose of each object and whether they had ever owned or used the object or one very similar. Participants were then presented with a series of statements associated drop-down boxes containing five possible responses (see Figure 9). Respondents were instructed to indicate which object was best described by the associated statement and how strongly the statement applied. There were options for strong, weak, and equal. The last could be used whether both objects were equally weak in that trait or equally strong. See Appendix C for the full set of survey pages.

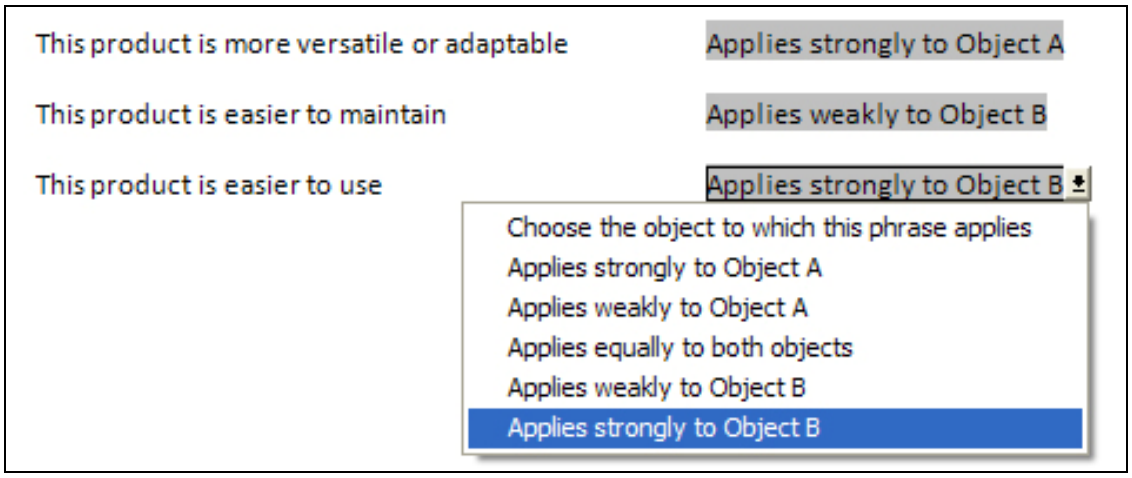

Figure 9. Survey phrase with dropdown box options

The objects were viewed only in comparison to ensure that the differences within the pairs were being tested, rather than any qualities of the overall product category. A Likert scale for each trait for each individual object was initially considered as a potential survey format, but a pilot study suggested that the objects were being ranked relative to other objects rather than relative to their opposing paired variant. In the pilot study individual differences between the original pairs were too small to detect relative to the differences from pair to pair. The differences between pencils and offices would have obscured any differences between modular and non-modular variants so the Likert scale approach was abandoned in favor of the direct comparison.

CHAPTER 4

RESULTS

4.1 Interview

4.1.1 General Observations

The interview subjects produced 200 word pairs in 161 unique sets. The 28 word pairs associated with the desks were removed since participants consistently found the desk images equally modular. The remaining words were sorted into 26 categories (see Section 3.4.3 for a description of the culling process). Table 4 presents the categories that emerged and the word pairs assigned to represent each category. The base word represents the trait most often associated with the modular variants of the object pairs.

Table 4. Categories of word pairs identified during interview phase

Category	Base word	Opposite
Coldness	Cold	Warm
Comfort	Comfortable	Uncomfortable
Complexity	Complex	Simple
Control	Limited Control	More Control
Cost	Costly	Cheap
Difficulty	Difficult	Convenient
Disassembly/Replacement	Replaceable	Non-disassemblable
Durability	Not Durable	Durable
Form/Function Emphasis	Focus on Function	Focus on Form
Functionality	High Quality	Average/Low Quality
Material	Synthetic	Natural
Newness	New	Old
Openness	Open	Closed
Parts	Many	Single
Permanence	Long Lasting	Disposable
Portability/mobility	Mobile	Immobile
Professional Level	Experienced/Professional	Novice/amateur
Seriousness	Serious	Fun
Size	Large	Small
Status Visibility	Hidden Status	Visible Status
Storage	Easy storage	Difficult storage
Style	Stylish	Unstylish
Sustainability	Sustainable	Unsustainable
Use Intensity	Intense	Casual
Versatility	Versatile	Focused
Specific	*Comparisons specific to the product type*	

Participants provided approximately five word pairs per object. The maximum number of pairs assigned to any one object was twelve and the minimum was three. The top categories in order from most to least popular were permanence, complexity, newness, versatility, professional level, and size. Section 3.4.3 provides more details on the precise process of transforming these word pairs into the trait descriptions used in the following survey. There are a few word pairs that did not find their way to the survey, however, that are still worth mentioning.

Two different participants mentioned some form of "status visibility" in relation to the weights. They used variations on "labeled" or "straightforward," indicating that it was easier to know what weight to expect when lifting the solid dumbbell as opposed to the adjustable dumbbell. The topic did not emerge often enough to incorporate into the survey but it is useful to note that modularity, by introducing degrees of freedom into a product, can make it more difficult for users to judge the current state of the product.

The participants often described the non-modular variant as easier to maintain. This result emerged counter to initial expectations, as Gershenson et al described the benefits of modularity to product lifecycle, including increased ease of maintenance (Gershenson et al., 1999). For example, without the benefit of a modular design, drivers would have to buy a whole new car every time they got a flat tire. This seemed like a strong indication that modularity would be perceived by users as enabling maintenance and this researcher expected the study to support this hypothesis.

However, where the researcher was expecting disposable products to be perceived as impossible to maintain, the participants saw them as lacking a need for maintenance. If broken, the product could be thrown away and replaced with a new version. More than one participant indicated that the non-modular variant was easier to maintain *because* it could not be repaired, only discarded. A quote from one participant is enlightening:

> I think probably A [is easier to maintain] . . . It's just looking pretty. If you do any kind of maintenance, I guess wipe it down. If anything goes

> wrong with that chair you pretty much have to throw it out. I mean if you get a crack in it, I don't think duct tape is going to fix that.

In several cases the participants described the modular variant as having a longer life in the same response where they identified the non-modular variant as easier to maintain.

4.2 Survey

4.2.1 General Observations

Ninety participants were recruited, with thirty-one people returning the surveys. Some trends were immediately obvious, while others required a more careful investigation of the properties of the relationships between the objects. Figure 10 depicts the responses across all objects in the survey. The green bars represent votes associating the trait with the modular variant. They gray bars are equal votes, and the red bars are votes associating the trait with the non-modular variant.

Three traits stand out with a strong pro-modular response. In the categories of complexity, replaceable parts, and versatility, participants overwhelmingly chose the modular variant as most representative of the listed trait. The first two traits, complexity and replaceable parts, are variations of those used to originally define modularity. Their application by participants to the predefined modular variants validates the object pair selection and indicates that the respondents perceive the relative modularity as intended, if not necessarily by that name.

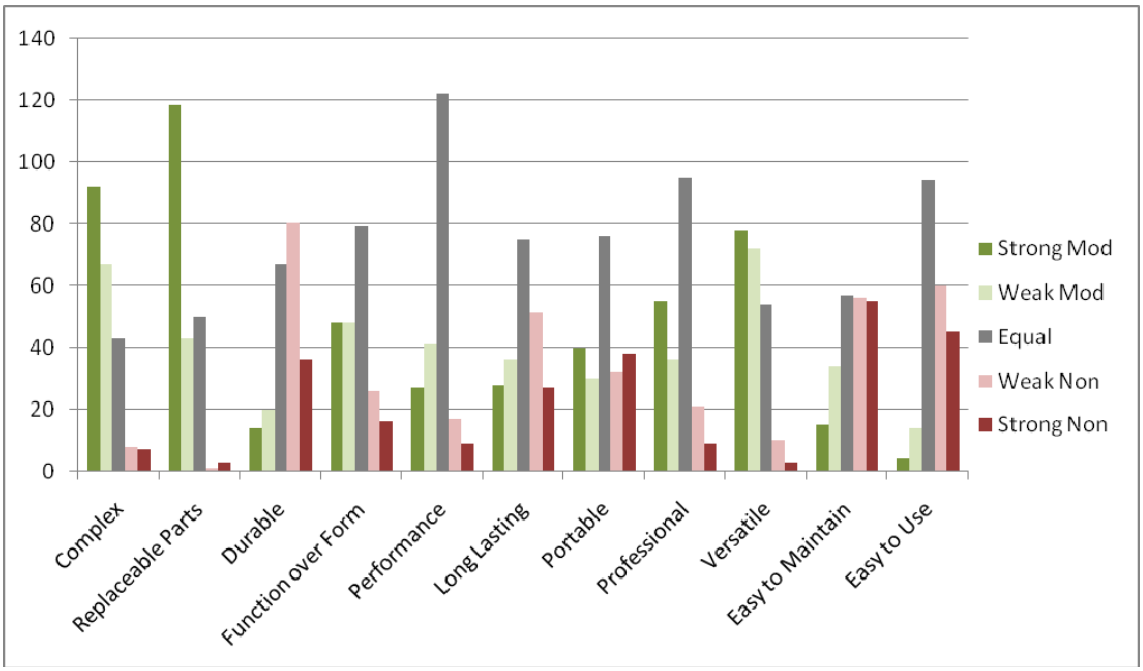

Figure 10. Count of survey responses for each trait across all products

The third trait strongly applied to modular variants in the survey, versatility, has previously been identified as a benefit for producers. From a manufacturing standpoint, modularity permits multiple configurations and thus allows the maker to more easily create a family of products to serve a variety of customer interests (Dahmus et al., 2001; Gershenson et al., 2003; Ulrich & Tung, 1991). Manufacturers use versatility to serve many needs simultaneously. Based on comments during the interview phase of this study, the users expect modular products to address a variety of needs over time. Participants indicated that the modular variant of the weights, the cameras, the offices, and the chairs all scored highly for versatility; all objects that were meant to be configurable and adaptable to changing needs.

There were three traits consistently applied to the non-modular variant in the pair, although the difference was not as great as for the previous traits. The non-modular variants were indicated to be easier to use, more durable, and easier to maintain than their more modular counterparts. This again supports the results from the interviews. That

non-modular variants are perceived as easier to use is not particularly surprising, given that they are also perceived as less complex. Interviewees and survey respondents alike found non-modular products to be more durable as well as easier to maintain, although the correlations are not as strong as for the first three traits discussed.

The other traits did not exhibit a strong bias towards either product. There are two different arrangements that lead to this condition. The survey responses could have consistently indicated that the two products are equally representative of the trait under consideration or a bias could be present for individual object pairs, but inconsistent in its application to the relative modularity. The results for "Performance" are an example of the second (see Figure 11), while the results for the "Long Lasting" trait are an example of the first (see Figure 12).

Each object pair was judged equal in "Performance" by most respondents, indicating, in the aggregate, users do not perceive an impact by modularity on an object's ability to perform its designated task. There are two caveats to this observation, however. First, it appears to be contradicted by the occasionally strong responses to the question regarding use by a professional. One would expect performance and professional application to be closely linked. However, cameras, chairs, and mops all had a noticeable bias for use by a professional (modular for the first two, non-modular for the third) that was not evident in their "Performance" scores. One respondent pointed out in a comment attached to the returned survey that performance applies to a particular intent and thus makes comparing variants of different purposes meaningless. This may not apply significantly in this case, however. The majority of respondents did not differentiate between the purposes of the variants. Respondents defined the same purpose for both variants 141 times out of 192 complete responses (not including 25 partial or skipped responses). The relationship between traits is discussed in more detail in section 4.2.5.

Figure 11. Survey responses for "Performance" trait

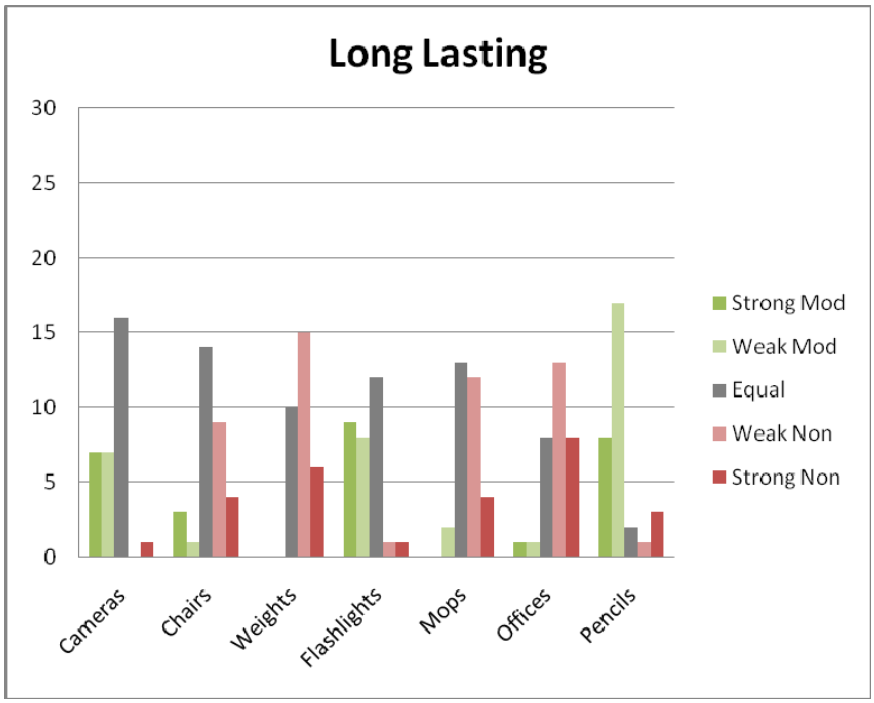

Figure 12. Survey responses for "Long Lasting" trait

4.2.2 Exceptions to General Observations

There are a few places where an object pair does not fit the general trends described above but only one where the results for an object pair run counter to the general trends. Results from the office, the flashlight, and the mop pairs each vary slightly from the overall results. The flashlights show the least difference in versatility, and were voted roughly equal in their durability. The mops show the least difference in replaceable parts and are roughly equivalent in ease of use. The offices show almost complete equality in terms of complexity and are close to equal in their ease of use. The offices are also the only object pair to run actively against a general trend with a slight bias towards modularity in their ease of maintenance. This anomaly fits well, however, with the discussions that emerged during the interview phase, specifically the idea that disposable variants were easier to maintain simply because they could not be maintained. The offices represent the extreme end of that scale. The non-modular variant in the office pair is a custom made wooden desk and shelf combination that is not a product to be easily disposed of and replaced when damaged. At this large size, the impact of modularity on product lifecycle processes may become significant as replacing the entire product has become too costly to be a viable alternative to basic repairs.

4.2.3 Predefined Categories

In an effort to further explore the impacts of modularity on perceived product traits of use and maintenance, the objects were examined for commonalities within certain categories. The products were organized into subcategories according to how they met a predefined theme (see Table 5). Similarities and differences across these categories are discussed below. Section 4.2.4 discusses the inverse process, groupings based upon commonalities in the data.

The modularity type, the size type, and the decomposition level categories are based on the typologies discussed in section 3.1. The motive power category is based on

the performance of the objects. External motivation comes from the user, such as pushing a mop or lifting a weight. Internal motivation is driven by more complex internal forces, such as batteries.

Table 5. Predefined object categories

Organization Criteria		
Subcategory	# of members	Members
Modularity Type		
Slot	5	Camera, Chair, Flashlight, Mop, Pencil
Sectional	1	Office
Bus	1	Weights
Size Type		
Finger	1	Pencil
Hand	3	Camera, Flashlight, Weights
Shoulder	1	Mop
Body	1	Chair
Environment	1	Office
Decomposition Level		
Use	3	Camera, Mop, Weights
Maintenance	4	Chair, Flashlight, Office, Pencil
Motive Power		
External	5	Chair, Mop, Office, Pencil, Weights
Internal	2	Camera, Flashlight

The first two categories are unevenly distributed. An effort was made at the start of the study to ensure that representatives of each category were included in the research, but a particular balance was not sought during the experiment's design. This leads to a situation where a single exemplar must represent an entire subcategory. The resulting comparisons are available in Appendix E3 for the curious reader, but should not be relied upon without further investigation.

The final two categories, decomposition level and motive power, are more evenly distributed and are discussed below. Some intriguing observations can be made but, again, further study would be necessary to test the emerging conclusions.

For these analyses, and others to follow, the survey responses were converted into numbers (see Table 6) and then averaged to obtain a single score for each category.

Table 6. Values assigned to survey responses

2	Applies strongly to the modular variant
1	Applies weakly to the modular variant
0	Applies equally to both variants
-1	Applies weakly to the non or less modular variant
-2	Applies strongly to the non or less modular variant

4.2.3.1 Decomposition Level: User Level versus Maintenance Level

At the decomposition level, the modular variants of the cameras, the mops, and the weights all have components that are meant to be swapped or replaced during typical use of the product. The other pairs all have varying degrees of replaceable parts, but these are not meant to be refilled or replaced as primary use actions.

It could be argued that the modular mop variant, the sheet mop, belongs in the maintenance category or, conversely, that the mechanical pencil belongs in the use category. Both have an active component that must be replaced periodically. The difference used here to distinguish the two and place them into separate categories is that the sheet mop dust pad is meant to be replaced multiple times in a single cleaning session whereas the pencil lead is meant to be refilled only after a great deal of writing and the eraser generally lasts even longer.

The other objects are a clearer fit for their respective subcategories. In the use category, the cameraman will swap lenses and flash attachments in a single photo shoot

and one person will often switch out weights on the dumbbell for different specific exercises in a workout. In the maintenance category, flashlight parts are replaced only when the batteries run down or the bulb burns out, while the office and the chair are disassembled only when something has broken. Figure 13 shows a comparison of the resulting categories.

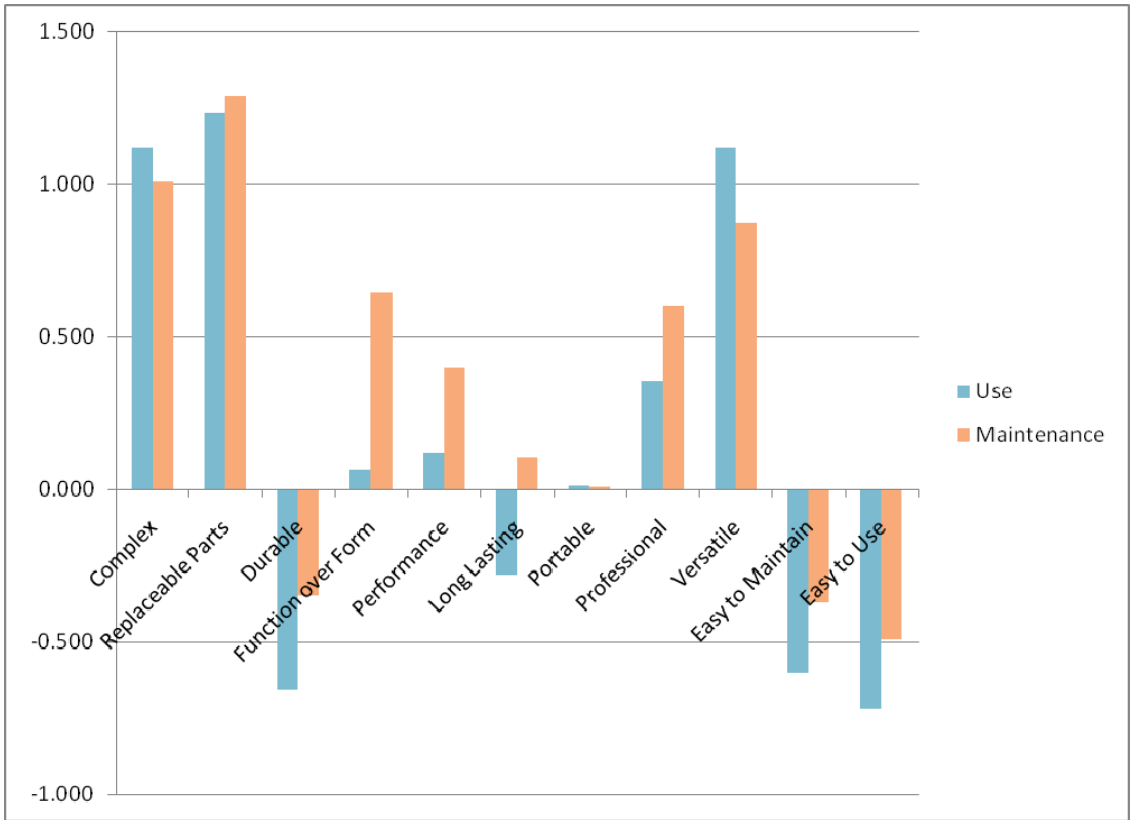

Figure 13. Comparison of trait response averages between decomposition level categories

The categories show little difference in most traits, matching the behavior of the group as a whole in terms of complexity, replaceable parts, durability, performance, long life, portability, professional use, versatility, ease of maintenance, and ease of use. Since complexity and replaceable parts are essentially our measures of modularity we would not expect those to vary by category. That the other traits listed above offer only minor

variations indicates that the level of decomposability does not affect those properties. It does however appear to affect the participants' perceptions of the focus on function over form. In that trait, the user level decomposable objects show almost no difference between modular and non-modular variants. In the maintenance level decomposition category, however, participants indicated that an emphasis on form over function tended to be stronger in the modular variant than the non-modular variant. The difference between the two average responses for these two categories is not large, just over 0.5, but it is curious. One might expect user level decomposability to have a more significant impact as the user is expected to interact with that feature more directly than with a feature of maintenance level decomposability. Indeed, as the interviews suggested, users are often willing to ignore maintenance level decomposability and simply discard the product and purchase a new one. Perhaps it is this very immediacy that requires designers to more carefully balance form and function at the user level than at the maintenance level. It is a question worth considering for future research.

4.2.3.2 Motive Power: Internal versus External

The objects for the next category were divided by the location of the primary motive power, external or internal. Externally motivated objects are driven by a force outside themselves and generate no independent motion; chairs, pencils, mops, offices, and weights all respond directly to the user's motion. The internally motivated objects respond to the user's touch, but are driven by more complex internal forces. The flashlights and cameras chosen here happen to be powered electronically by batteries, but electricity is not a necessary prerequisite to membership in the internal motive subcategory. A windup watch would also be considered internally motivated.

Figure 14 shows the results of comparing the response averages between the internally motivated objects and the externally motivated objects. As with the decomposition level analysis, several traits show little difference within each subcategory

or the overall averages. Complexity and replaceable parts are once again roughly equal between the categories. This time ease of maintenance is also roughly equal. The traits of emphasis on function over form, performance, and versatility show slightly larger gaps, but none larger than 0.5.

The differences that do emerge in this comparison are more noticeable than those discussed for decomposition level. Four traits show a disparity between the categories greater than 0.5 and three of those are greater than 1.

Durability shows a disparity of 0.648, with the externally motivated objects showing a bias towards durability in the non-modular example. The internally motivated objects slow almost no difference in durability across modularity.

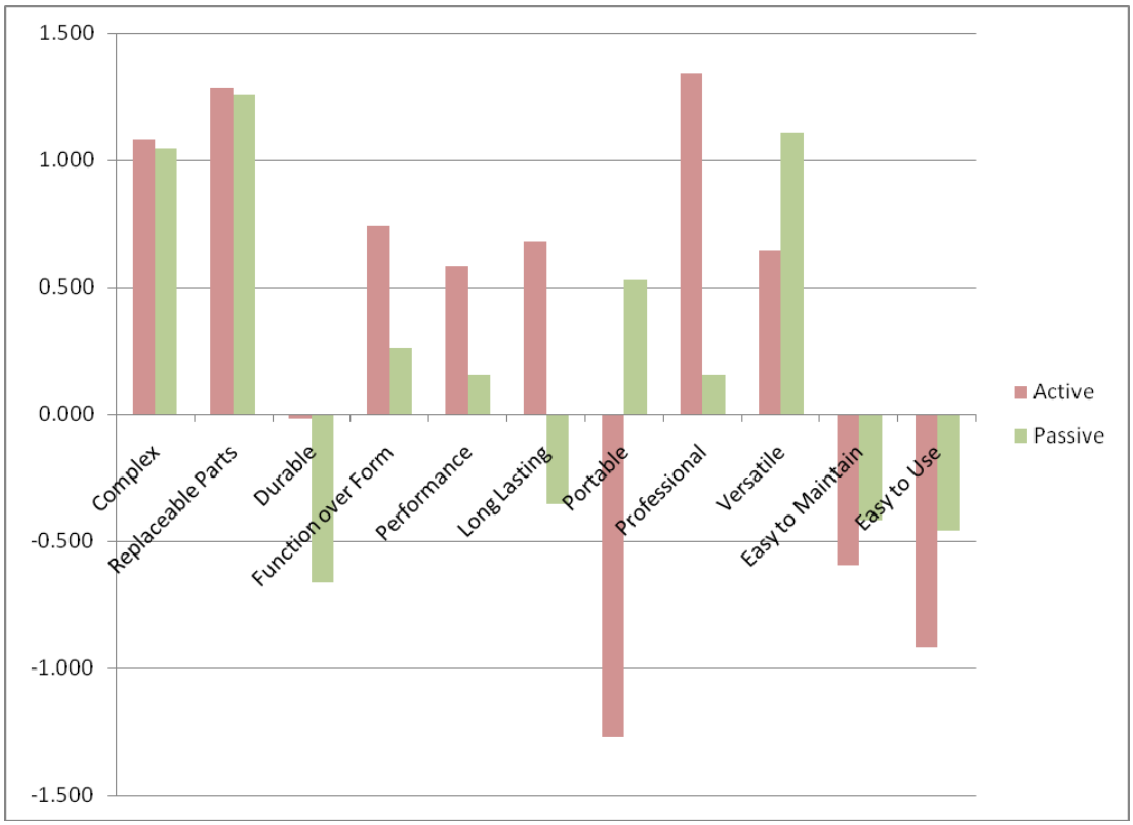

Figure 14. Comparison of trait response averages between motive subcategories

The addition of moving parts to the externally motivated objects is a more significant change than for the internally motivated objects. Dividing an externally motivated object into multiple parts introduces breaks and weaknesses that are not necessary for the primary function of the object. The non-modular pencil, chair, and weight are solid objects with no moving parts. The non-modular mop and the non-modular office both possess simple moving parts, but their more modular partners each have additional joints, breaks, and points of separation not found in the non-modular variant. The internally motivated pairs, on the other hand, are equally divided. The main difference between the modular variant and the non-modular variant of the cameras and the flashlights is not number of parts but the ability to remove and replace those parts. Many of the weaknesses and breaks found in the modular variant of the internally motivated product already existed in the non-modular variant; increasing the degree of modularity simply made them more accessible. Thus applying a modular design to internally motivated objects does not incur the same cost in durability that is imposed on externally motivated objects.

The results for which variant will last longer are similar, although greater in disparity with a difference of 1.032 between the two averages. The participants expected the non-modular variants of the externally motivated objects to last longer than their counterparts. In contrast, they expected the modular variants of the internally motivated objects to last longer than their counterparts. This could again be related to the introduction of separations into the externally motivated objects. During the interviews, several participants remarked that it would be easier to lose parts of the modular variants of the mops and the weights.

The expectations of which variant would be most likely to be used by a professional showed a similar discrepancy, with a difference of 1.183. The externally motivated objects showed little difference between modular and non-modular variants for use by a professional, but the internally motivated objects were strongly biased towards

the modular variant, the strongest bias found on this chart. It is important to note, however, that the final average score for professional use by the externally motivated objects emerges from conflict rather than consensus. For example, the participants expected professionals to prefer the *modular* variant in the case of the chairs and the *non-modular* variant in the case of the mops. Thus, while it can be observed that professionals are expected to prefer modular internally motivated objects over non-modular internally motivated objects, no such generalization, in either direction, can be made regarding the modularity of externally motivated objects.

The greatest discrepancy between the motive subcategories is found in the portability trait. Participants identified the modular variant of externally motivated objects as slightly more portable than the non-modular variant, but they found the non-modular variant of the internally motivated objects to be much more portable than the modular variant. There is a spread of 1.800 between the two averages. This, as with the durability discrepancy, may be attributable to the different way modularity is enacted in a externally motivated object versus an internally motivated object. Modularity almost always adds infrastructure to an object – the latches, bolts, connection points, and other interfaces that enable the parts to separate and come together again (Fixson, 2007). In the externally motivated objects the additional infrastructure is countered by the ability to disassemble the object for transportation. Of the externally motivated objects, the only pair to receive more than a handful of votes for the non-modular variant was the chair, which is not intended to be disassembled for any purpose except repair. In the case of the sheet mop handle and the cubicle walls, easy shipment could be considered one of the driving forces for making the object modular. In contrast, the modularity of the camera is designed to increase versatility, to allow the camera to serve multiple purposes with a variety of lenses and flashes. This has a twofold impact on the portability of the internally motivated object. First, the infrastructure adds size and weight. Second, the attachments are intended to meet greater professional-level requirements. The flash in a

point-and-shoot camera is not expected to do nearly the work demanded of the SLR camera flash. That added performance adds weight and size as well. The flashlight, although not as extreme, is subject to the same pressures. The material is heavier and the various connections, threads, and gaskets increase the size slightly while offering no advantage in portability through disassembly.

4.2.4 Emergent Categories

It is also possible to approach object categories from the other direction, to define the categories based on shared traits and then attempt to identify common features of the objects so grouped. Figure 15 depicts the trait response averages for each object pair. Objects are then grouped by observing similar response patterns, as represented by the charted lines.

Using the standard deviation between the average trait values leads to a series of pairs as displayed in Table 7. The full table of deviations is available in Appendix E4.

Table 7. Emergent Categories

Group		Std Dev
Flashlights	Pencils	0.564
Mops	Offices	0.602
Cameras	Chairs	0.689
Weights		N/A

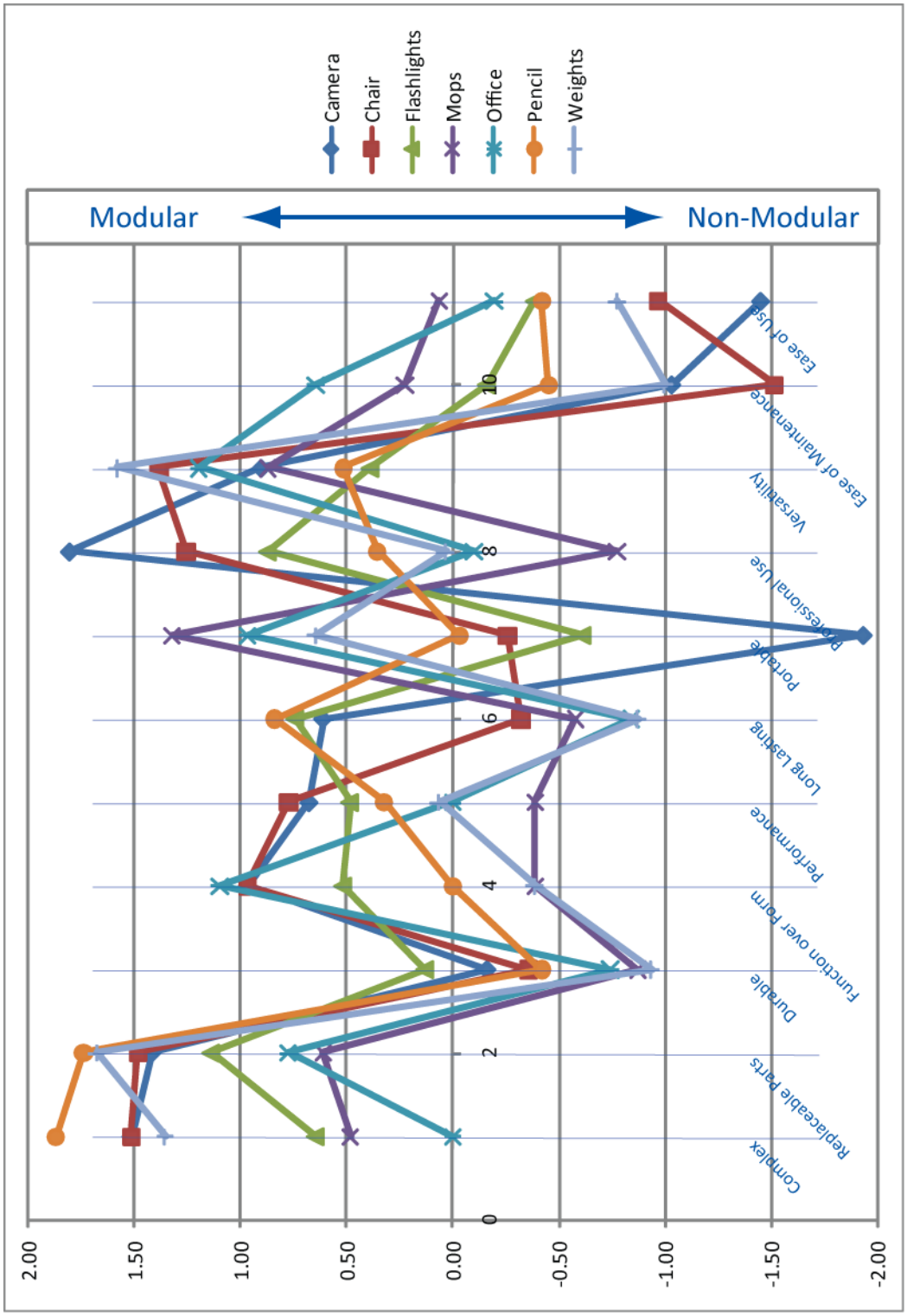

Figure 15. Trait averages

The camera and chair pairs have a tight overlay with the exception of the "portability" and "long lasting" values, as seen in Figure 16. Besides those scores, the two are almost identical. It is difficult, initially, to see what these two objects have in common. Examining the extremes in their scores may help. Cameras and chairs easily scored the highest of any objects in professional use, meaning that survey participants believed the modular variant was the most likely to be used by a professional and believed it more strongly of these two objects than of any of the other objects presented. They also had the highest scores for performance, tied with each other for second highest score for emphasis of function over form, and achieved the lowest scores for both ease of maintenance and ease of use. They also had relatively high scores in complexity and versatility as well.

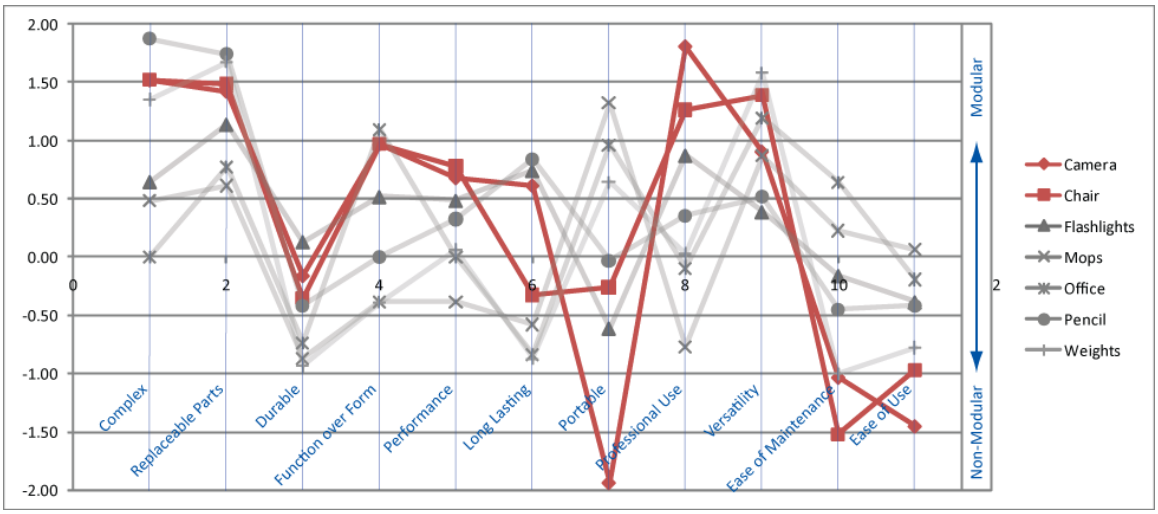

Figure 16. Trait averages, highlighting the Camera/Chair grouping

These scores apply to two objects, the modular and the non-modular variants. In the case of the cameras and the chairs, the non-modular variants are meant for a casual or

amateur setting while the modular variants are intended for a more formal, professional setting. This is reinforced by the majority of the responses to the question of purpose. Cameras and chairs received the most number of different purpose descriptions for the two variants. Mops came in a close third in number of different purposes but scored on the other end of the scale from cameras and chairs in almost every trait. This would initially appear to contradict the idea that diverging purposes can explain the extreme scores of the cameras and the chairs. However, mops variants were also assigned the opposite purposes. The non-modular mop was assigned the more professional, thorough, and time-consuming purpose whereas in cameras and chairs those purposes went to the modular variant. With opposite purposes, the fact that mops received scores opposite those of chairs and cameras suggests that the context of the object has a strong impact on the perceived emphasis on form over function, performance quality, professional use, ease of maintenance, and ease of use. The broad spread between the extremes suggests that modularity can be used to augment/exacerbate or dampen/mitigate these tendencies depending on how it is applied.

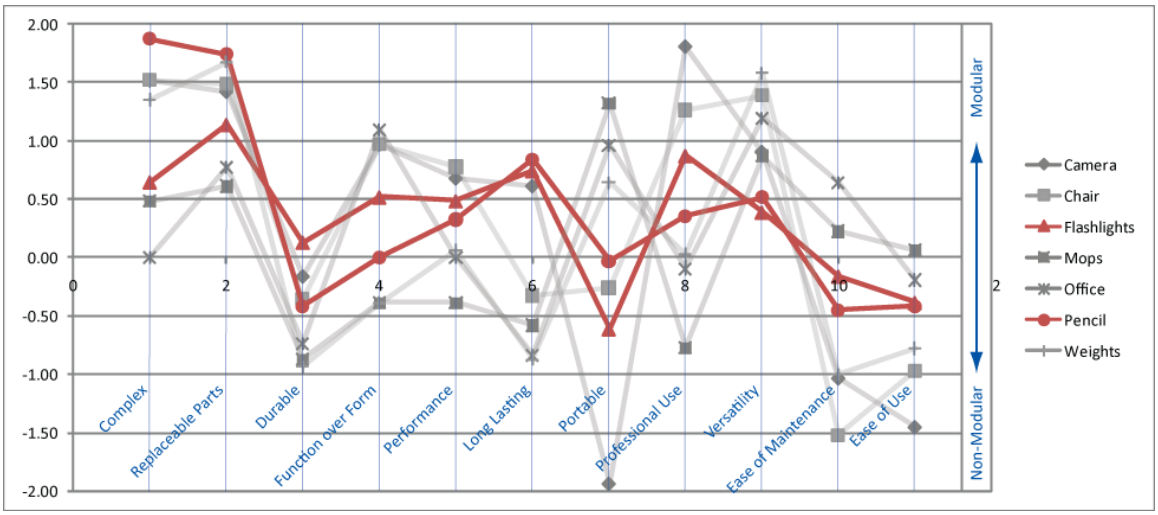

Figure 17. Trait averages, highlighting the Flashlight/Pencil grouping

The flashlight and pencil combination is less mysterious. They are similar in size and both applications of modularity appear intended to extend the useful life of the product by permitting lead to be refilled and batteries, blown bulbs, and worn erasers to be replaced. Indeed the trait of long life is where the two are most similar. Survey results emphasize long life in the modular variant for these two products more so than any other products. The opposite is true for versatility, the modular variants are least emphasized as compared to other products. For these two products, modularity was used to extend the useful life of the objects without adding any other significant functionality. Even though these objects received the lowest versatility scores, they still received *positive* versatility scores. Survey participants considered the modular variants slightly more versatile than their counterparts.

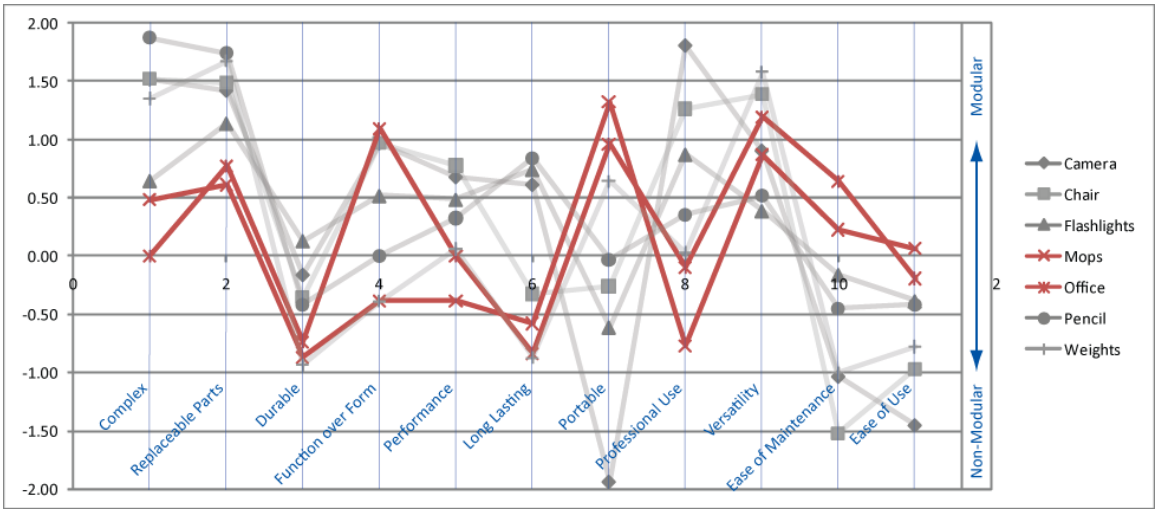

Figure 18. Trait averages, highlighting the Mops/Offices grouping

Mops and offices, like the camera/chair pairing, form an odd couple. With the exception of the emphasis on function over form where they occupy opposite ends of the

range, the responses for offices and mops present almost identical charts, yet sheet mops and cubicles are not often thought of in the same category. Here again the extreme scores can be informative.

Mops and offices have several scores close to the zero line. Only the flashlight deviates less from zero. In several cases mops and offices are both closer to the zero line than any other object. This is true for the traits of complexity, replaceable parts, performance, and professional use where they score the lowest of the various objects. It is also true of ease of use, where they score the highest of any object. In other words, the modular variant and the non-modular variant show less differentiation than can be found in the other product sets. There are a few noteworthy exceptions, however.

In versatility, the mops and offices occupy the middle of the group. Only the camera scored closer to the overall average. The modular variants of both mops and offices exhibited versatility despite their relatively low scores in complexity and replaceable parts. The mops and offices also showed the highest scores for portability, a strong indication that the modular variant in both cases is more portable than the non-modular variant. These two scores reflect the design intents of the modular variants chosen for this survey. The sheet mop and the cubicle share a common design need for versatility and portability that is reflected in these scores. The sheet mop is meant to serve for both wet and dry floor cleaning. It comes in a small box and must be assembled to be used. One participant appreciated the ability to take the sheet mop apart and store it under the sink when the cleaning was done. The cubicle is designed to be able to fill multiple office structure needs, to be taken apart and rearranged as personnel demands shift. Accounting for the difference in scale, these objects meet similar needs.

Mops and offices earned some of the lowest scores in both durability and long life, exceeded only, in both traits, by the weights. The versatility and portability came at a cost in strength. They also occupy opposite extremes in the score for emphasis on function over form. The offices had the highest score and the mops tied with the weights

for the lowest score. It is unclear why these two objects, so similar in all other categories, would diverge so dramatically at this trait. The difference in scale could have an impact, but why this might be so is not immediately obvious.

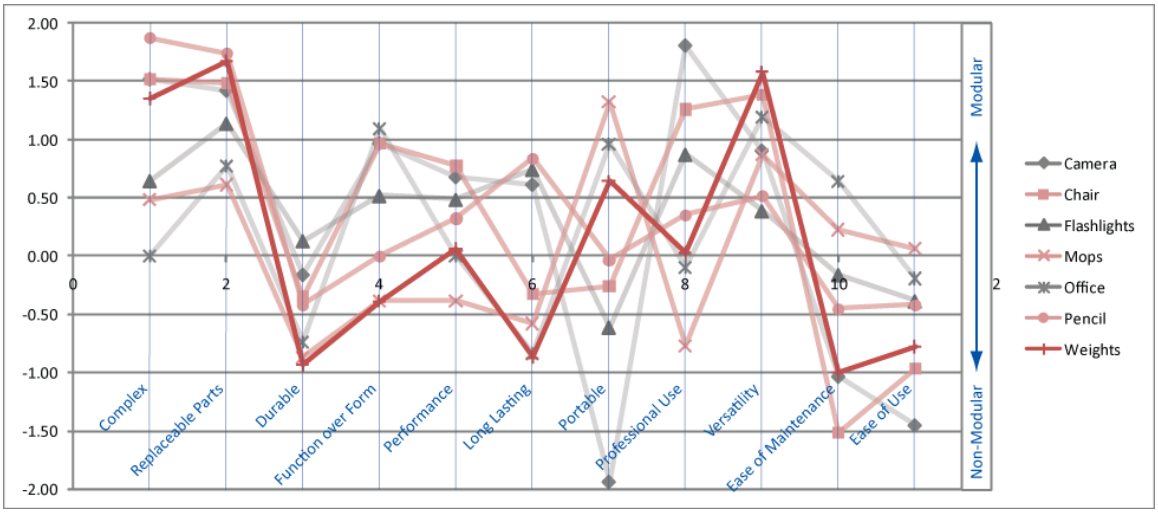

Figure 19. Trait averages, highlighting the weights

The weights remain in a category of their own. They have some similarities to the chairs, the pencils, and the mops, but do not have a tight fit anywhere. The weights, the pencils, and the chairs – each with a single-piece non-modular variant – are the highest scoring objects for complexity and replaceable parts. While the pencil's modularity increases its lifespan, the modularity of the chairs and the weights increased their versatility at the cost of durability and life span. Here the weights share the low end of the range with the mops. Multiple interview participants expected to lose parts of the modular mop and the modular weight, a concern not raised about the other objects. Along with the camera, these are the only objects in the group that permit long term removal of components. The other products must contain all components to function and are generally stored fully assembled, if at all. The modular weights, mops, and cameras can be disassembled for storage. The cameras and the weights are intended to be used

with less than the full complement of components – swapping one lens for another or mixing and matching available weight discs. The cameras, however, received high scores for durability. Cameras are complex and fragile instruments in general. Mops and weights are not, and this could explain why weights and mops are grouped at the bottom of the scale while cameras, which share the potential for lost components, still received high scores.

4.2.5 Trait Comparisons

The behavior of the average scores visible in Figure 15 suggests specific relationships between the traits. An investigation of coefficient of determination (r^2) values based on these average scores, depicted in Table 8, confirms that there are several strong relationships. The values greater than 0.60 are highlighted in green.

Table 8. Trait Score Relationships: Coefficient of Determination values

	Complex	Replaceable Parts	Durable	Function over Form	Performance	Long Lasting	Portable	Professional	Versatile	Easy to Maintain	Easy to Use
Complex	N/A	0.82	0.05	0.02	0.34	0.22	0.28	0.28	0.00	0.68	0.42
Replaceable Parts	0.82	N/A	0.05	0.01	0.36	0.14	0.22	0.26	0.02	0.61	0.41
Durable	0.05	0.05	N/A	0.26	0.59	0.70	0.65	0.59	0.40	0.06	0.15
Function over Form	0.02	0.01	0.26	N/A	0.40	0.02	0.26	0.42	0.00	0.01	0.18
Performance	0.34	0.36	0.59	0.40	N/A	0.33	0.72	0.92	0.01	0.50	0.61
Long Lasting	0.22	0.14	0.70	0.02	0.33	N/A	0.54	0.34	0.67	0.03	0.08
Portable	0.28	0.22	0.65	0.26	0.72	0.54	N/A	0.90	0.09	0.31	0.67
Professional	0.28	0.26	0.59	0.42	0.92	0.34	0.90	N/A	0.01	0.45	0.75
Versatile	0.00	0.02	0.40	0.00	0.01	0.67	0.09	0.01	N/A	0.13	0.08
Easy to Maintain	0.68	0.61	0.06	0.01	0.50	0.03	0.31	0.45	0.13	N/A	0.68
Easy to Use	0.42	0.41	0.15	0.18	0.61	0.08	0.67	0.75	0.08	0.68	N/A

Professional use appears to have the strongest correlations, with performance and portability respectively, and a relatively weaker, but still strong correlation to ease of use. Figure 20 shows a graph of the professional use scores versus the scores for performance, portability, and ease of use.

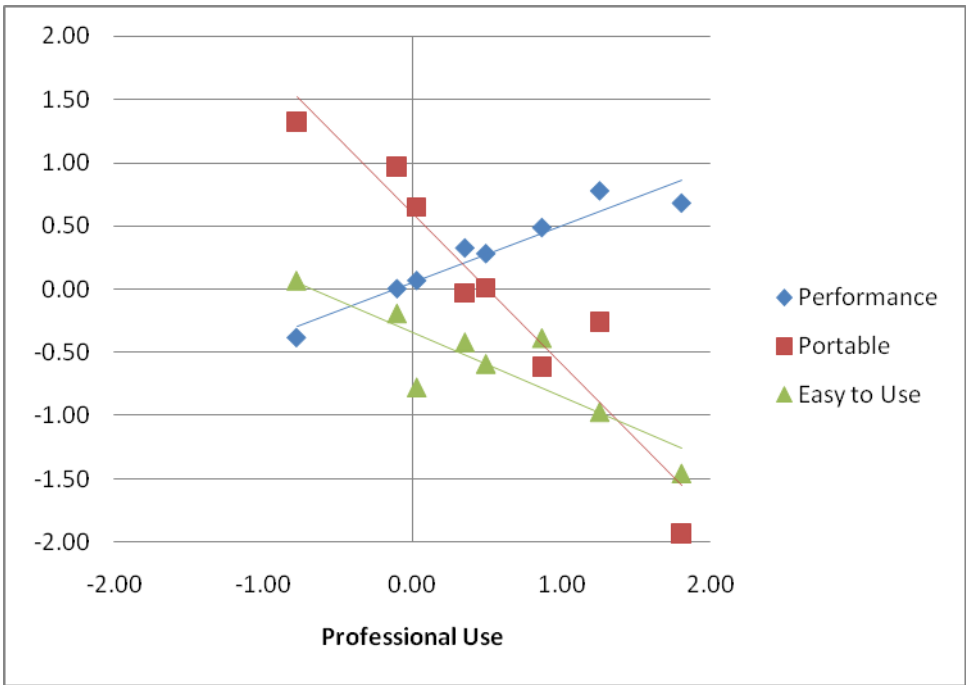

Figure 20. Professional use values relative to performance, portability, and ease of use

When considering the charts in this thesis it is important to remember that a higher value does not necessarily mean that the modular variant of one object has more of that trait than the modular variant of a different object, merely that the difference between the modular variant and the non-modular variant is greater. The numbers are relational not absolute. The difficulties this presents are discussed in greater detail in section 5.4.1. For the purposes of the immediate discussion, the important factor to consider is the relative change (delta). A positive correlation, as seen between professional use and performance, the blue line in Figure 20, indicates that the traits are shared. For example,

the variant in the pair that participants believed most likely to be used by a professional is also expected to perform better. A negative correlation indicates the traits are inversely related. In the case of the traits displayed above, the stronger the perception an object variant is meant for a professional user, the less likely it is expected to be perceived as easy to use or portable. Therefore, a portable, user-friendly camera is not considered an expert's camera.

The r^2 values in Table 8 show the strength of the relationships but not their direction. Figure 21 below illustrates the strongest correlations. The corresponding scatter plots can be found in Appendix E5.

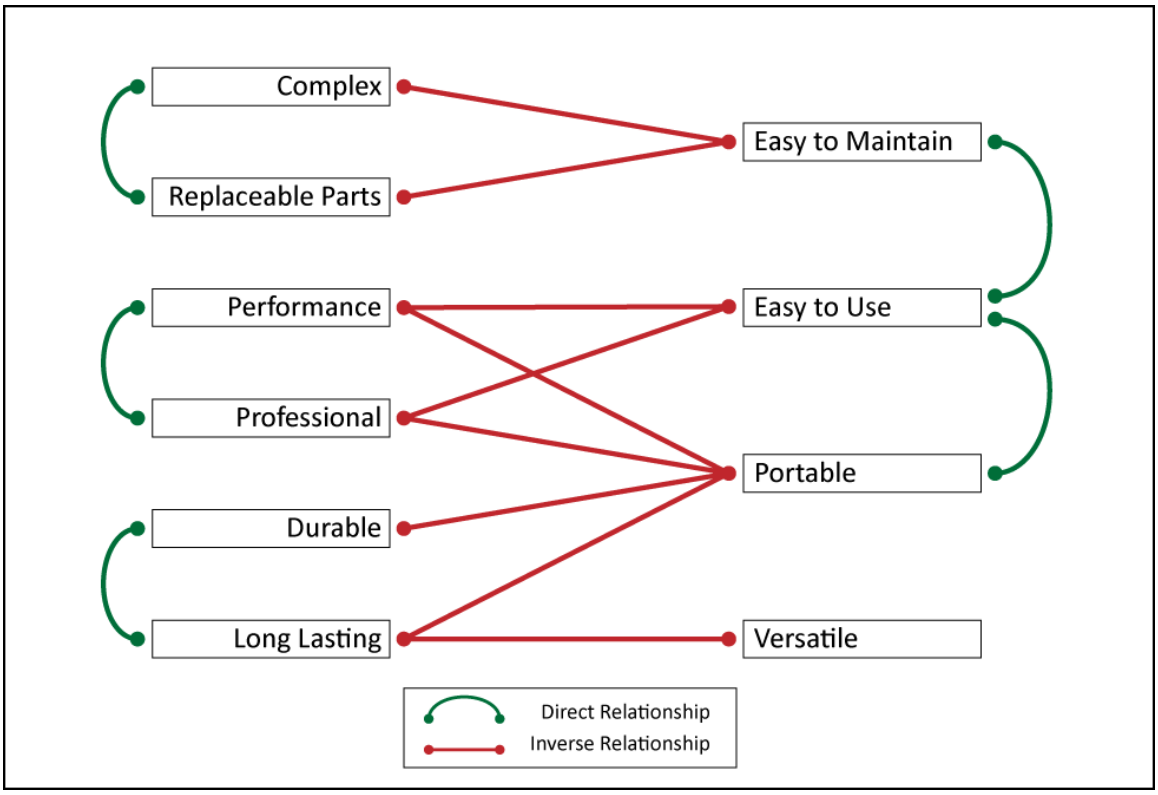

Figure 21. Trait Relationships

The relationships between the traits occur within the context of modularity, although this does not imply that they occur *only* within the bounds of modularity. It

may be the case that portability and durability will always be tradeoffs, but what is demonstrated here is that they are tradeoffs specifically with respect to changing degrees of modularity. An increase in portability due to a change in degree of modularity will likely be accompanied by a decrease in durability. This is useful for designers working with modular products, whether these relationships apply in other situations or not.

CHAPTER 5

DISCUSSION

5.1 General Modularity Influences on Product Perception

Modularity can be a design decision but so, too, can the appearance of modularity. A product can be made modular to meet an end or, as Schilling (2000) found, modularity can emerge in a product through pressures of the commercial environment without deliberate intent. Whether a product is modular by demand or by evolution, the decision of how to present modularity remains in the designer's hands. It is not an empty decision. The research in this thesis, at its most basic, demonstrates that the appearance of modularity impacts consumer impressions of the use and maintenance of a product. There are a few traits expected to behave consistently relative to the perceived modularity, but specific contexts must also be considered when deciding how to treat modular designs.

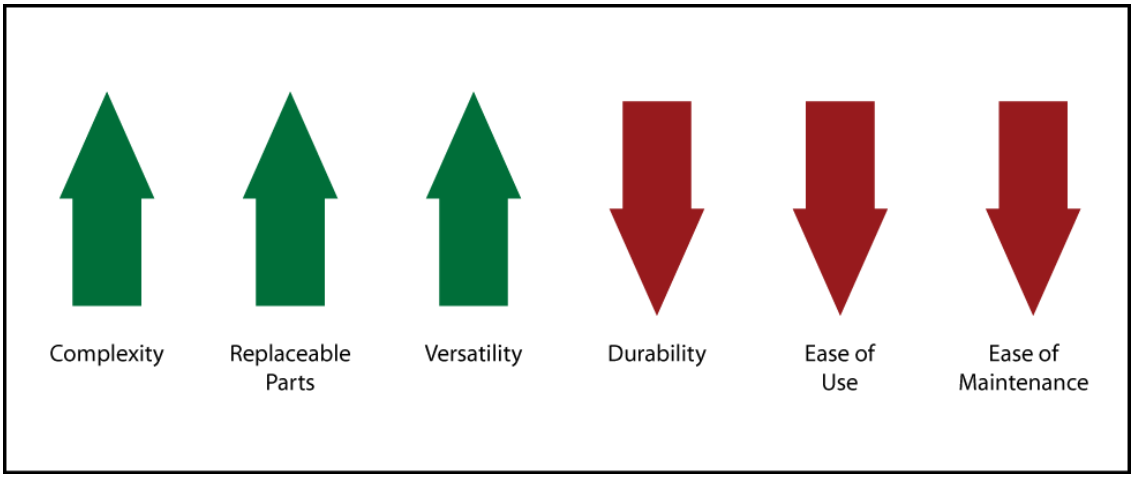

Figure 22. General trends associated with modular design

In general, products displaying features of maintenance and user level decomposable modularity will be seen as more complex, more likely to have replaceable parts, and more versatile and adaptable than similar products that do not appear modular. However, those same modular products will be perceived as less durable, more difficult to use, and more difficult to maintain.

The finding that modular products are perceived as more difficult to maintain requires further clarification as it appears to contradict earlier research. The contradiction, however, is in the interpretation of the word "maintenance." It is important to note that the results presented in this thesis are based on perceptions, not objective measurements. The interview responses suggested that the participants were determining difficulty of maintenance in terms of what could be done to the product rather than the level of effort involved in maintaining a certain level of performance. Several participants commented that the non-modular product was easier to maintain because there was nothing one could do if anything went wrong except to discard it and buy a new one. From that perspective, there is no maintenance just replacement. The product that *cannot* be maintained becomes the one that is easiest to maintain.

The trait relationships support this interpretation; as complexity and replaceable parts increase, ease of maintenance decreases. The very presence of replaceable parts accompanies an increased expectation of difficult maintenance. The designer needs to be aware of the inverse relationship between modularity and perceived ease of maintenance but should not fall into the trap of assuming that the perceived traits are the true traits.

The designer must choose which of these features are more important to convey. The designer can then obscure or illuminate the modularity of the product to achieve the desired end. Note that it is not necessary to increase or decrease the actual degree of modularity, only its perceived presence. These are general effects, however. The specifics of the product context will affect how modularity impacts perception. For instance, a large scale product may not face the same stigma related to maintenance

found in smaller scale products. This research points to several similar effects, but there are more to be discovered.

5.2 Modularity in Motive Context

5.2.1 Internally Motivated and Externally Motivated Products

The degree of internal motivation has an effect on how the contributions of perceptible modularity will be interpreted. When increasing the perceptible modularity of an internally motivated object such as a camera, the designer can expect users to find the new version suited more towards professionals and longer lived at a cost to portability. The internally motivated nature of the product – moving parts, power sources, and interaction points – magnifies certain aspects of the changes wrought by higher modularity while diminishing others.

Externally motivated objects, being less dynamic, emphasize other effects. The designer working with the modularity of externally motivated objects will find that it decreases perceived durability and product life while suggesting greater portability. Unlike the internally motivated objects, modularity in externally motivated objects appears to have little effect on perceptions of professional use.

5.2.2 Products for the Amateur and the Expert

The nature of the intended user can also have a significant impact on the perception of modular design. When the modularization of a product is intended to increase its appeal to professionals and other expert users many of the influences of the modular design are magnified. The differences between modular variants and non-modular variants in perceived complexity, replaceable parts, versatility, ease of use, and ease of maintenance are even more pronounced if the modular product is also intended for a professional. They are diminished if the non-modular product is intended for the professional user.

The designer creating a product for the professional should be aware of these effects and account for them.

5.3 Trait Relationships in the Context of Modular Design Decisions

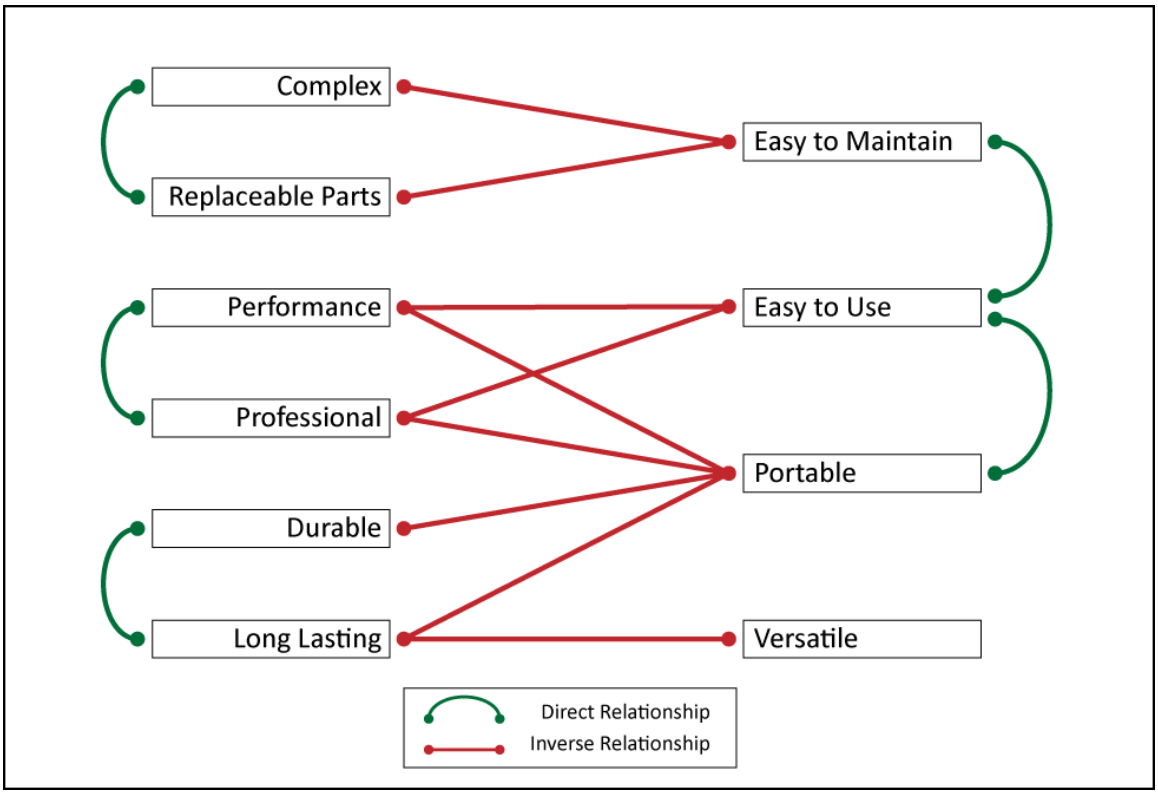

Figure 23. Trait Relationships in Modular Context

Modularity does not just serve as an influence but can be a context in and of itself. Within the context of a modular design the traits investigated in this thesis have specific and identifiable behaviors. Understanding these relationships, depicted in Figure 23, can help designers best invoke the specific traits they seek.

5.4 Directions for Future Research

5.4.1 Tool Limitations

Several decisions were necessary to pursue the research for this thesis and each had an impact on what could and could not be learned from the tools. First, the thesis established a starting point and used a relatively small sample to do so. Establishing specific and detailed trait relationships would require a more focused approach with a larger sample population and could be a useful next step in modularity research.

The common caveat regarding statistics must also be emphasized: correlation does not imply causation. It is possible that modularity is not the driver in these relationships. For example, certain objects might require more maintenance in general which then demands modularity in the guise of replaceable parts and complexity. The study of modularity would benefit from tests designed to identify which aspect of the relationships described in this thesis is the cause and which is the effect.

The survey itself is relational. The numbers generated refer to the differences between comparative products rather than absolute and independent values. The cameras are not more portable than the pencils, the survey respondents are more certain of the differences between the camera types. Establishing a specific value for modularity and the traits associated with it is not a trivial task. This research considered a broad range of objects and, because of this, was limited in its ability to focus on specific scores. An absolute scale would have obscured the differences between variants by highlighting differences between objects. The decision to use the relative scoring was deliberate, but limits the comparisons that can be made, such as comparisons across varying product types.

Finally, the survey used pictures to ask participants about their impressions. Questions about ownership and use established that the majority of participants had experience with both objects selected, but even so recollection is known to be faulty.

This survey produced information about expectations, not about true product properties. Managing expectations and impressions are part of the designer's task and the information is valuable. However designers would also benefit from more objective data about the behavior of modular products. There are research opportunities for observing participants working with real products directly.

5.4.2 New Questions Raised

The results of this research validate previously held assumptions of product modularity. One might expect modularity to increase versatility, but expecting is different from knowing. Much has been studied of the impact of modularity on manufacturing processes, but the same degree of attention has not been paid to the impact on the user. The answers to many of the questions discussed in this paper have been assumed but it was important that they be demonstrated before research could move forward. This thesis serves as a starting place, and from here there are many directions to explore.

This thesis has demonstrated that modularity does have an effect, but cannot describe that effect with precision. The questions it has answered have enabled new ones to be brought forward:

1. What are the specific relationships between a modular design and usage and maintenance traits?
2. What are the objective effects on the use of a modular design? How do these effects differ from the perceived effects?
3. What are the specific drivers in the trait relationships? This thesis has established correlation, but causation remains uncertain.

The research in this thesis has also hinted at other opportunities for exploration:

4. How does scale affect the impact of modularity? How do these relationships change as objects grow larger?

5. What effect does the modular format – slot, sectional, or bus – have on the observed relationships?
6. What is the impact of modular design on the user's ability to identify a product's current state or arrangement?

This thesis has demonstrated that modularity can have a significant impact on product impressions, but designers still have much to learn before the modular product's relationship to the user is as well understood as its relationship to the manufacturer.

APPENDIX A

TYPOLOGIES

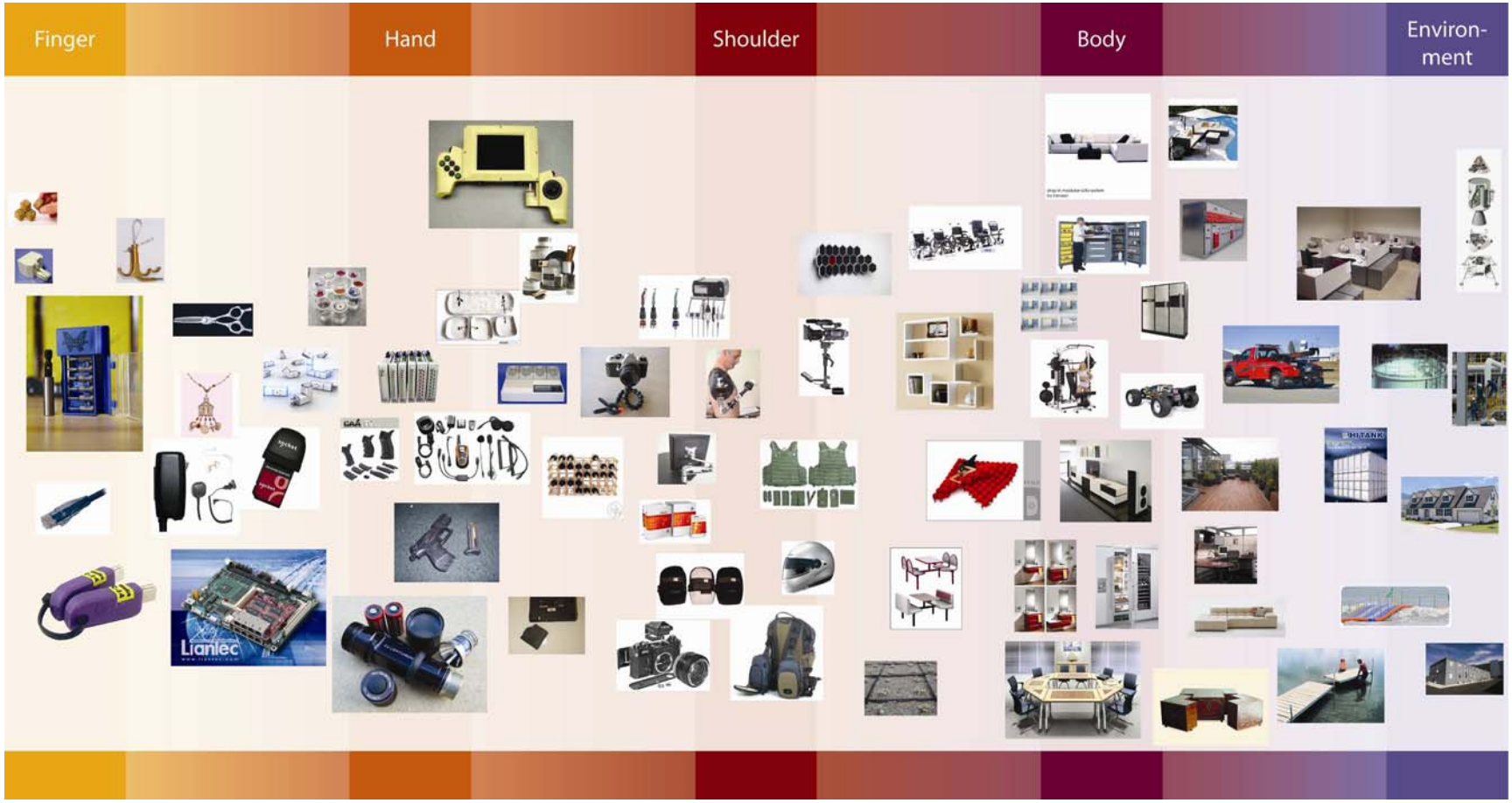

Figure 24. Size Typology

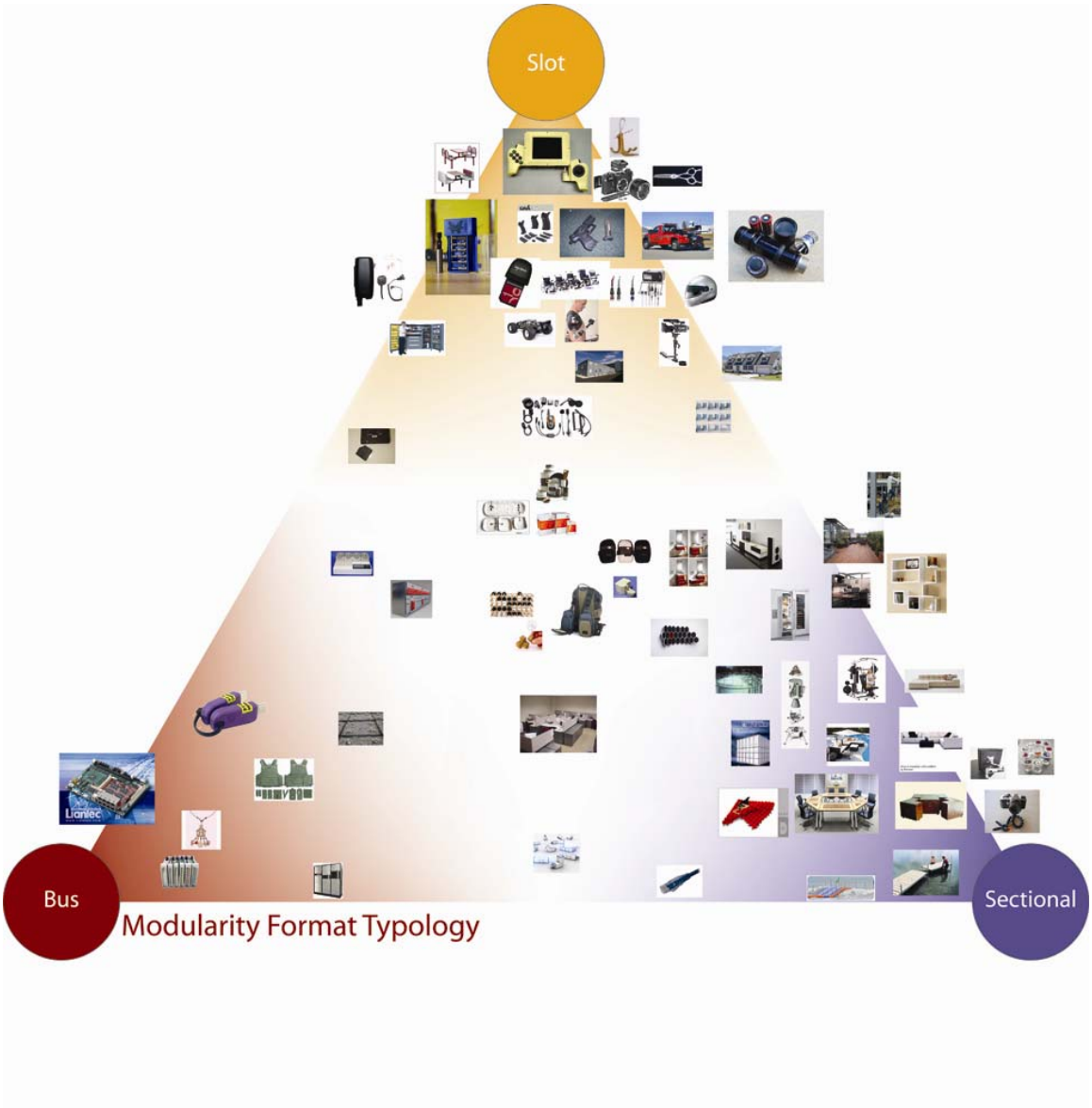

Figure 25. Format Typology

APPENDIX B

INTERVIEW

B1. The Interview Question Prompts

Each participant will be shown a pair of products and then asked the following questions.

I. Questions concerning individual products within the pair

a. Have you ever owned this product or one similar?
b. What do you believe is the primary function of this object?
c. What do you believe is the primary setting where this product would be used?
d. How would you use this product?
e. How would you maintain this product?

II. Questions concerning product pair comparisons

a. Why do you think someone might choose to purchase Product A over Product B?
b. Why do you think someone might choose to purchase Product B over Product A?
c. Do you feel one product would be easier to use than the other? Why?
d. Do you feel there are any (other) differences between these products in terms of use?
e. Do you feel one product would be easier to maintain? Why?
f. Do you feel there are any (other) the differences between these products in terms of maintenance?

III. Generating word pairs

a. Please suggest as many opposing descriptions as you believe could be used to distinguish these two products. For example, if Picture A showed a carrot and Picture B showed a candy bar, possible opposites might include healthy/unhealthy; natural/processed, or even yucky/yummy.
b. Which of the word pairs you suggested do you believe are most important to the use of the objects? Why?
c. Which of the word pairs you suggested do you believe are most important to the maintenance of the objects? Why?

IV. Questions concerning modularity

(This portion of the interview occurred after the above questions had been asked of all pairs)

a. We are particularly interested in studying the impact of modularity on product use and maintenance. We define a modular product as one comprised of groupings of components that are independent from other such groupings, and which may, themselves, consist of smaller such groupings.
b. Do you feel either of these products is more modular than the other? Why or why not?
c. (if yes to b) What features of this product led you to pick it as more modular than the other?

B2. Interview Images

B

Source: stock.xchange

A

A

B

Source: www.livingroom.org.au; stock.xchange

A

B

Source: Mahogany Masterpieces.com; ComputerDesks.com

A

B

Source: Advanced Interior Designs; Spacify

A

B

Source: Diamond Relocation; David Langdon

A

B

Source: Expedition Exchange; HotRef

A

B

Source: Personal Photo; AbilityOne

A

B

Source: stock.xchange

APPENDIX C

SURVEY

The surveys were delivered over email to participants. The first question required a write in response and space was offered for this. The rest of the questions used dropdown boxes. Participants selected the appropriate response to each question, saved the file, and returned the survey to the researcher.

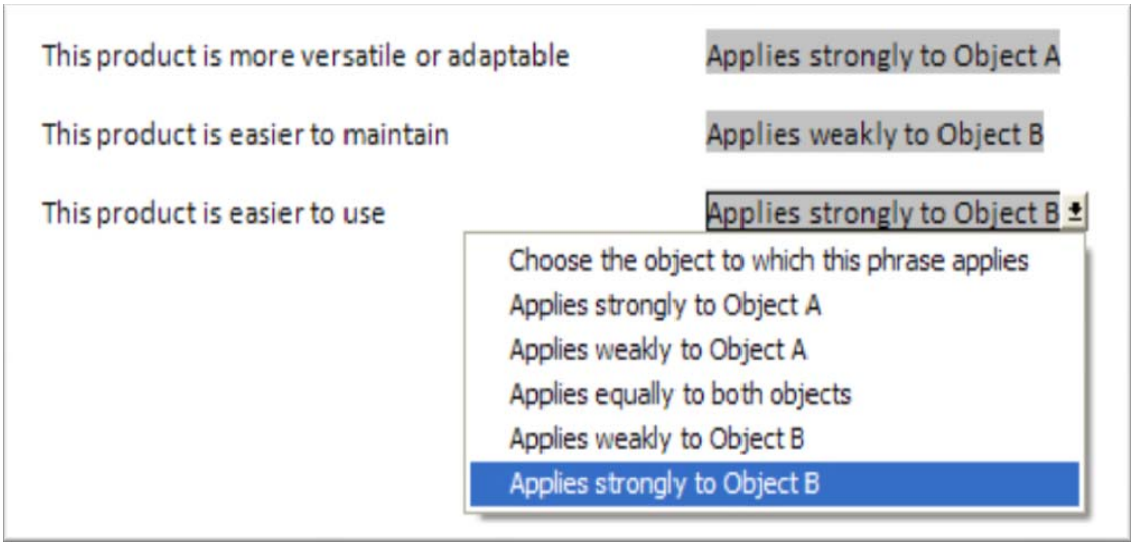

Figure 26: Example of dropdown menu used in survey

Thank you for your interest in volunteering for this research study. The purpose of this research study is to investigate the impact of product design differences on people's experience using and maintaining the product. Your participation will help improve our understanding of product design and could aid in the design of future products to better balance manufacturer needs with user needs.

The attached questionnaire should take approximately 15-20 minutes to complete. There are no correct or incorrect answers. Your responses will be kept anonymous. Please do not include your name anywhere in the responses. Please try to answer the questions in one sitting, but if you need to take a break, we suggest you do so at the end of a section rather than in the middle.

The survey is below. Each question is marked with a gray box for your answer. To return the survey, save the document and attach it in an email addressed to rsmith33@gatech.edu or robertjsmith@gmail.com. Your responses will be separated from your email and the email will be deleted so it will not be possible to match a questionnaire with a particular person. Participants' names and any other facts that might point to them will not appear when results of this study are presented or published.

If you have any questions or concerns, do not hesitate to contact me either via email (rsmith33@gatech.edu) or by phone (703.609.2735).

Thank you again for your interest.

Kevin Shankwiler, Primary Investigator

Robert Smith, Co-Investigator

Please read the consent form attached to the original email before continuing any further. As we cannot gather signatures over email, the return of this survey to the investigators will be construed as an indication of your consent to participate in this research study.

_____ What is the primary purpose of this item? _____

??? Have you ever used this item or one very similar? ???

Object A

Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
This product emphasizes function over form	Choose the object to which this phrase applies
This product will perform better	Choose the object to which this phrase applies
This product will last longer	Choose the object to which this phrase applies
This product is more portable	Choose the object to which this phrase applies
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

_____	What is the primary purpose of this item?	_____
???	Have you ever used this item or one very similar?	???

Object A

Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
This product emphasizes function over form	Choose the object to which this phrase applies
This product will perform better	Choose the object to which this phrase applies
This product will last longer	Choose the object to which this phrase applies
This product is more portable	Choose the object to which this phrase applies
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

_____	What is the primary purpose of this item?	_____
???	Have you ever used this item or one very similar?	???

Object A

Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
This product emphasizes function over form	Choose the object to which this phrase applies
This product will perform better	Choose the object to which this phrase applies
This product will last longer	Choose the object to which this phrase applies
This product is more portable	Choose the object to which this phrase applies
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

_____	What is the primary purpose of this item?	_____
???	Have you ever used this item or one very similar?	???

Object A

Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
This product emphasizes function over form	Choose the object to which this phrase applies
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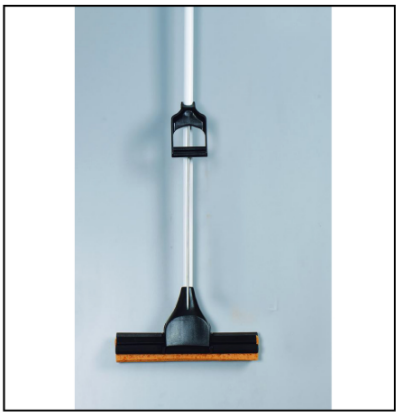
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

_____	What is the primary purpose of this item?	_____
???	Have you ever used this item or one very similar?	???

Object A



Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
This product emphasizes function over form	Choose the object to which this phrase applies
This product will perform better	Choose the object to which this phrase applies
This product will last longer	Choose the object to which this phrase applies
This product is more portable	Choose the object to which this phrase applies
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

_____	What is the primary purpose of this item?	_____
???	Have you ever used this item or one very similar?	???

Object A

Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
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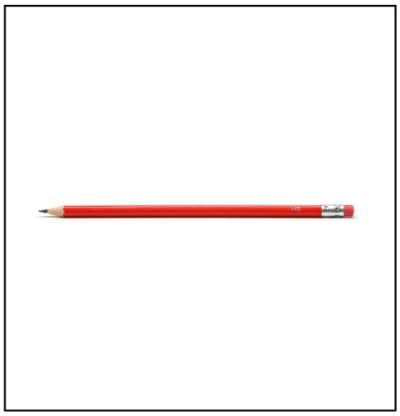
This product is more portable	Choose the object to which this phrase applies
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

_____	What is the primary purpose of this item?	_____
???	Have you ever used this item or one very similar?	???



Object A

Object B

This product is more complex	Choose the object to which this phrase applies
Parts of this product can be replaced	Choose the object to which this phrase applies
This product is more durable	Choose the object to which this phrase applies
This product emphasizes function over form	Choose the object to which this phrase applies
This product will perform better	Choose the object to which this phrase applies
This product will last longer	Choose the object to which this phrase applies
This product is more portable	Choose the object to which this phrase applies
This product would be used by a professional	Choose the object to which this phrase applies
This product is more versatile or adaptable	Choose the object to which this phrase applies
This product is easier to maintain	Choose the object to which this phrase applies
This product is easier to use	Choose the object to which this phrase applies

APPENDIX D

INTERVIEW DATA

Table 9. Interview Descriptor Pair Responses

Pair	More Modular	Less Modular	Use vote	Mx Vote
Pencils	mechanical	non-mechanical		
Pencils	heavy duty	non-heavy duty		
Pencils	unnatural	Natural		
Pencils	cool	warm		
Pencils	permanent	non-permanent		
Pencils	longer lasting	temporal		y
Pencils	more involved	less involved		
Pencils	convenient	inconvenient		y
Pencils	nonprofessional	professional	y	
Pencils	no vary line weight	control line weight	y	
Pencils	contemporary	classic		
Pencils	refillable	non-refillable		y
Desks	temporary	permanent		
Desks	movable	immovable		y
Desks	easy to transport	hard to transport		y
Desks	disassemblable	non-disassemblable		y
Desks	contemporary	classic		
Desks	inexpensive	expensive		
Desks	nondurable	durable		
Desks	less space	more space	y	
Desks	specific	general	y	
Desks	light	heavy		
Cameras	Professional	consumer		
Cameras	control, more	control, less	y	
Cameras	addons, more	addons, less	y	y
Cameras	big	small		
Cameras	interchangeable lenses	noninterchangeable lens	y	
Cameras	heavy duty	less heavy duty		y
Cameras	heavy	light		
Cameras	bulky	sleek		
Cameras	image quality, better	image quality, decent	y	
Cameras	versatile	non-versatile	y	
Cameras	expensive	cheap		
Chairs	ergonomic	ergonomic, less	y	
Chairs	serious	fun		
Chairs	permanent	less permanent		
Chairs	visually hard	visually soft		
Chairs	adjustable	nonadjustable	y	
Chairs	expensive	inexpensive		

Pair	More Modular	Less Modular	Use vote	Mx Vote
Table 9 (continued)				
Chairs	many parts	one part		y
Offices	cheap	expensive		
Offices	less permanent	permanent		y
Offices	less durable	durable		y
Offices	cool	warm		
Offices	contemporary	vintage		
Offices	closed	open		
Offices	confined	less confined	y	
Weights	flexible	inflexible	y	
Weights	disassemblable	nondisassemblable	y	
Weights	less heavy duty	more heavy duty		
Weights	potential part failure	???		y
Weights	more comfortable	less comfortable		
Weights	many parts	one part		y
Weights	soft handle	hard handle		y
Flashlights	permanent	nonpermanent		
Flashlights	expensive	cheap		
Flashlights	durable	nondurable		
Flashlights	metal	plastic		y
Flashlights	better performance	average performance		
Flashlights	replaceable (batteries)	nonreplaceable		y
Flashlights	bright	less bright	y	
Mops	disassemblable	nondisassemblable		y
Mops	easy package	needs no package		
Mops	less heavy duty use	more heavy duty use	y	
Mops	replaceable cleaning surface	more permanent cleaning surface	y	
Mops	less durable cleaning surface	more durable cleaning surface	y	
Mops	convenient	inconvenient		
Mops	cheap	expensive		
Pencils	automatic	manual	y	y
Pencils	digital	analog	y	
Pencils	engineer	artist		
Cameras	prosumer	amateur	y	
Cameras	business	cute		
Cameras	less mobile	mobile	y	
Cameras	functional	shiny		y
Desks	home office	office	y	
Desks	mobile	stationary	y	

Pair	More Modular	Less Modular	Use vote	Mx Vote
Table 9 (continued)				
Desks	casual	business		y
Desks	modern	classic		
Desks	inexpensive	expensive	y	
Chairs	history of computing	history of ID		
Chairs	functional	attractive	y	
Chairs	monotone	colorful		
Chairs	flexible	stiff		y
Offices	corporate	freelance		
Offices	cold	warm		
Offices	structured	unstructured	y	
Offices	closed	open		
Offices	modular	built-in		y
Weights	light	heavy		y
Weights	mobile	stationary	y	
Weights	pieces	block		y
Flashlights	heavy duty	disposable	y	
Flashlights	police officer	old lady		y
Flashlights	function	form		
Mops	casual	intense	y	y
Mops	disposable	permanent		
Mops	fad	standard		
Pencils	Plastic	Wood		
Pencils	Synthetic	Natural		
Pencils	Easy	Hard	y	y
Pencils	New	Old		y
Cameras	multiple	single		
Cameras	large	small	y	
Cameras	???	compact		
Cameras	experienced	avg joe/inexperienced		
Cameras	complex	simple	y	y
Cameras	serious	fun	y	
Desks	college	professional	y	
Desks	informal	formal		
Desks	setting stuff on	storage		
Desks	small	big		
Chairs	function	art		
Chairs	black and white	colorful		
Chairs	serious	fun		

Pair	More Modular	Less Modular	Use vote	Mx Vote
Table 9 (continued)				
Chairs	work	play	y	
Chairs	complex	simple		y
Chairs	mobile	immobile/stationary		y
Chairs	dynamic	static	y	y
Offices	sterile	warm		
Offices	customizable	set	y	y
Offices	office	showcase		
Offices	Synthetic	Natural		
Weights	dynamic	static	y	y
Weights	many	single		y
Weights	unlabeled	labeled	y	
Speakers	serious	playful	y	
Speakers	many	single		y
Flashlights	long life	short life	y	y
Flashlights	many	single		
Flashlights	sustainable	disposable	y	y
Mops	pieces	single		y
Mops	sanitary	nasty	y	y
Mops	disposable	non-disposable	y	
Pencils	new	old		y
Pencils	technologically advanced	untechnologically advanced	y	y
Pencils	cool	uncool		
Pencils	new school	old school		
Pencils	fun	not fun	y	
Cameras	hard	easy	y	
Cameras	not simple	simple	y	y
Cameras	large	small		
Cameras	time consuming	quick	y	
Desks	new	antique		y
Desks	unstable	solid	y	
Desks		craftsmanship	y	
Desks	machine made	hand flavor		
Desks	student	distinguished		
Chairs	function	appearance		
Chairs	comfortable	uncomfortable	y	
Chairs	unstylish	stylish		
Chairs	function	new age		
Offices	cheap	costly		

Pair	More Modular	Less Modular	Use vote	Mx Vote
Table 9 (continued)				
Offices	new	old		
Offices	easy to assemble	cumbersome	y	y
Offices	average	prestigious		
Weights	complex	simple	y	
Weights	multiple uses	single use	y	
Weights	costly	cheap		y
Flashlights	complex	simple	y	
Flashlights	many pieces	no pieces		y
Flashlights	multiple uses	single time use	y	y
Flashlights	green	not green		
Mops	quick	long	y	
Mops	ease	cumbersome	y	y
Mops	new	old		
Mops	not earth friendly	earth friendly		
Mops	younger user	older generation		
Pencils	sharp	dull	y	
Pencils	grownup	childish		
Pencils	indisposable	disposable		y
Desks	new	old		
Desks	fake	real		y
Desks	technologically oriented	non technologically oriented	y	y
Desks	impermanent	permanent		
Cameras	difficult	easy	y	y
Cameras	big	small	y	
Cameras	smart	stupid		y
Cameras	long term	short term		y
Cameras	high functionality	low functionality		y
Chairs	cold	warm		
Chairs	every day	specialty	y	y
Chairs	complex	easy		y
Chairs	function	form	y	y
Chairs	comfortable	uncomfortable		
Chairs	sad	happy		
Offices	cold	warm		
Offices	cheap	expensive		y
Offices	modern	traditional		
Offices	semipermanent	permanent		y
Weights	new school	old school		

Pair	More Modular	Less Modular	Use vote	Mx Vote
Table 9 (continued)				
Weights	less straightforward	straightforward	y	
Weights	complicated	easy	y	y
Flashlights	old	new		
Flashlights	complicated	easy	y	y
Flashlights	ugly	cute		
Flashlights	indisposable	disposable		y
Mops	new	old		
Mops	disposable	indisposable	y	y
Mops	compact	not space saving		
Mops	light use	heavy duty	y	y

APPENDIX E

SURVEY DATA

Table 10. Survey Raw Data

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	To take photos from long range	to take photos and be easily portable	y	y
Chairs	As an ergonomic seat	As a decorative seat	y	n
Weights	Weight for exercise	Weight for exercise	y	y
Flashlights	Portable ability to shine light	portable ability to shine light	y	y
Mops	Clean floors with aid of static electricty	Clean floors with aid of water	y	y
Offices	Maximize working space	To maximize working space and look pleasant	y	y
Pencils	To write with precision with ability to erase	To write with ability to erase	y	y
Cameras	empty	empty	empty	empty
Chairs	empty	empty	empty	empty
Weights	empty	empty	empty	empty
Flashlights	empty	empty	empty	empty
Mops	empty	empty	empty	empty
Offices	empty	empty	empty	empty
Pencils	empty	empty	empty	empty
Cameras	taking photos	taking photos	y	y
Chairs	sitting at a desk	decorative furniture	y	n
Weights	weight lifting	weight lifting	y	y
Flashlights	lighting	lighting	y	y
Mops	cleaning floors	cleaning floors	y	y
Offices	area for working	area for working	y	y
Pencils	writing	writing	y	y
Cameras	film	photography	y	y
Chairs	office seating	general seating	y	y
Weights	bodybuilding exercise	aerobic exercise	y	y
Flashlights	professional maint flashlight	household flashlight	y	y
Mops	household mop	industrial cleaning mop	y	y
Offices	administrative desk	professional desk	y	y
Pencils	mechanical pencil	standard pencil	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	To create photographs	to create digital photographs	n	y
Chairs	to provide a place to sit	to provide a place to sit	y	n
Weights	for use during weight lifting	for use during weight lifting	n	y
Flashlights	provide a light source	provide a light source	y	y
Mops	clean a floor/surface	clean a floor/surface	y	y
Offices	provide space for office work	provide space for office work	y	y
Pencils	To record hand-written information	To record hand-written information	y	y
Cameras	High quality CUSTOMIZED photos	Fast & EASY photos	y	y
Chairs	longterm COMFORTABLE seat	SHORT TERM c style seat	y	y
Weights	Muscle tone maintenance	Muscele tone maintenance	y	y
Flashlights	provide HIGH INTENSITY portable light	provide SHORT TERM portable light	y	y
Mops	FAST cleaning of hard surfaces	THOROUGH cleaning of hard surfaces	y	y
Offices	Perform long term mental work	Perform long term mental work	y	y
Pencils	modifiable writing	modifiable writing	y	y
Cameras	Photography	photography	y	y
Chairs	Sitting	Sitting	y	n
Weights	Weightlifting	Weightlifting	y	y
Flashlights	Handheld Light	Handheld Light	y	y
Mops	Floor Cleaning	Floor Cleaning	n	y
Offices	Office furniture	Office furniture	y	n
Pencils	mechanical pencil	Pencil	y	y
Cameras	SLR Camera	Digital Camera	n	y
Chairs	Chair	Chair	y	y
Weights	Weight	Weight	n	y
Flashlights	Flashlight	Flashlight	y	y
Mops	Swiffer Sweeper	Mop	y	y
Offices	cube furniture	Office furniture	y	y
Pencils	mechanical pencil	Pencil	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	takes photos	takes photos	n	y
Chairs	sit on it	sit on it	y	y
Weights	exercise with it	exercise with it	y	y
Flashlights	makes light	makes light	y	y
Mops	clean floors - dry method	clean floors - wet method	y	y
Offices	storage - mostly books	storage - mostly books	y	y
Pencils	writing	writing	y	y
Cameras	take photographs	take photographs	y	y
Chairs	to provide a comfortable seat	to provide a certain look	y	n
Weights	for weightlifting various weights	for weightlifting one weight	n	y
Flashlights	provide light	provide light	y	y
Mops	provide easy clean up	to clean a floor thoroughly	y	y
Offices	organize space in office	organize space in office	n	n
Pencils	writing in permanent ink	writing with erasable material	y	y
Cameras	to take pictures by professional photographers	to take pictures by most people	y	y
Chairs	to sit on y a computer used mostly in offices	to sit on by a desk or table	y	y
Weights	to work out upper body	to work out upper body	y	y
Flashlights	provide light	to light up your way	y	y
Mops	clean floors	clean floors	y	y
Offices	place to get work done and store books	place to get work done and store books	y	y
Pencils	to write	to write	y	y
Cameras	to take professional photos	to take digital pictures	y	y
Chairs	Ergonomic chair - proper seated position	chair to sit	y	n
Weights	free weight lifting	free weight lifting	y	y
Flashlights	Flashlight	Flashlight	y	y
Mops	clean floors	clean floors	y	y
Offices	workspace	workspace	empty	empty
Pencils	writing utensil	writing utensil	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	to take pictures	to take pictures	n	y
Chairs	to sit in	to sit in	y	n
Weights	Weightlifting	Weightlifting	y	y
Flashlights	personal illumination	personal illumination	y	n
Mops	cleaning floors	cleaning floors	y	y
Offices	Facilitate office work	Facilitate office work	empty	empty
Pencils	writing	writing	y	y
Cameras	professional photography	amature photography	y	y
Chairs	long period sitting	stylish seating	y	n
Weights	exercise	exercise	y	y
Flashlights	yes	light	y	y
Mops	floor cleanng	Floor Cleaning	y	y
Offices	desk	desk	y	y
Pencils	write	write	y	y
Cameras	empty	to take pictures	empty	y
Chairs	to sit in	empty	y	empty
Weights	Weightlifting	empty	y	empty
Flashlights	to provide light	empty	y	empty
Mops	empty	to clean	empty	y
Offices	empty	to store things	empty	y
Pencils	to write	empty	y	empty
Cameras	taking pictures	taking pictures	y	y
Chairs	seat	seat	y	n
Weights	weight	weight	y	y
Flashlights	Flashlight	Flashlight	y	y
Mops	dusting a floor	cleaning a floor	y	y
Offices	workspace	workspace	y	n
Pencils	writing	writing	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	take pictures	take pictures	y	y
Chairs	to sit	chair	y	n
Weights	weighlifting	Weightlifting	y	y
Flashlights	Flashlight	Flashlight	y	y
Mops	mop	mop	y	y
Offices	desk	desk	y	y
Pencils	pencil	pencil	y	y
Cameras	take professional pictures	take quick photos for the individual	y	y
Chairs	to sit and work for long periods of time	art, to look at and make comments about	y	n
Weights	to develop strength	to develop strength	y	y
Flashlights	portable light	portable light	y	y
Mops	clean the floor	clean the floor	n	y
Offices	works space and storage	work space and storage	y	n
Pencils	writing	writing	y	y
Cameras	take close up pictures	take pictures	n	y
Chairs	provide support	sit on	y	n
Weights	for exercise	for exercise	n	y
Flashlights	provide light	provide light	y	y
Mops	clean floors	wash floors	y	y
Offices	officed work space	office work space	n	n
Pencils	to write and erase	to write and erase	y	y
Cameras	Photography	photography	n	y
Chairs	office chair	crazy chair	y	n
Weights	lifting weights	lifting weights	y	y
Flashlights	Flashlight	Flashlight	y	y
Mops	dust mop	regular mop	y	y
Offices	desk	desk	y	y
Pencils	writing	writing	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	taking high quality pictures	taking pictures	y	y
Chairs	sitting	Sitting	y	y
Weights	exercise	exercise	y	y
Flashlights	lighting	lighting	y	y
Mops	cleaning floors	cleaning floors	y	y
Offices	office space	office space	y	y
Pencils	writing	writing	y	y
Cameras	taking professional-quality digital picutres	a digital camera for everyday use	n	y
Chairs	to provide a seat	to provide a seat	y	n
Weights	Weightlifting	Weightlifting	y	y
Flashlights	Flashlight	Flashlight	y	y
Mops	mopping linoleum floors	mopping linoleum floors	y	y
Offices	offices storage & organization	home storage & organization	y	y
Pencils	writing and mechanical drafting	writing & drawing	y	y
Cameras	taking photos	taking photos	y	y
Chairs	provide support for sitting	provide support for sitting	y	n
Weights	weight resistance training	weight resistance training	y	y
Flashlights	provide illumination	provide illumination	y	y
Mops	cleaning floors	cleaning floors	y	y
Offices	performing office work	performing office work	y	y
Pencils	writing	writing	y	y
Cameras	taking pictures	taking pictures	y	y
Chairs	sitting	Sitting	y	y
Weights	lifting weights	cartoon pratfalls	y	y
Flashlights	spotlighting deer	brightening dark things	y	y
Mops	cleaning floors	mopping	y	y
Offices	working	working	y	y
Pencils	writing hate mail	writing love letters	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	take pictures	take pictures	y	y
Chairs	to sit in	to sit in	y	y
Weights	build/tone muscle	build/tone muscle	y	y
Flashlights	provide light	provide light	y	y
Mops	clean floors	clean floors	y	y
Offices	workstation	workstation	y	y
Pencils	write	write	y	y
Cameras	taking photos	taking photos	n	y
Chairs	sitting	sitting	y	y
Weights	muscle building	muscle building	n	y
Flashlights	illumination	illumination	y	y
Mops	floor cleaning	Floor Cleaning	y	y
Offices	working surface and storage	working surface and storage	y	n
Pencils	writing	writing	y	y
Cameras	empty	taking photographs	empty	y
Chairs	used for sitting	empty	y	empty
Weights	to lift and exercise	empty	y	empty
Flashlights	to give light	empty	y	empty
Mops	empty	cleaning floors	empty	empty
Offices	empty	to hold things Storage	empty	y
Pencils	a pencil, for writing and drawing	empty	y	empty
Cameras	to take pictures	to take pictures	n	y
Chairs	for sitting	for sitting	y	y
Weights	strength training	strength training	y	y
Flashlights	portable light	portable light	y	y
Mops	clean floors	clean floors	y	y
Offices	starage and work space	starage and work space	y	y
Pencils	write and erase	write and erase	y	y

Table 10 (continued)

Objects	Purpose Mod	Purpose Non	Use Mod	Use Non
Cameras	to take pictures	to take pictures	y	y
Chairs	to be sat in	to add a modern artistic flair to a room	y	y
Weights	to be lifted	to be lifted	y	y
Flashlights	to provide a portable light source	to provide a portable light source	y	y
Mops	cleaning floors	cleaning floors	y	y
Offices	to provide an area for office work	to provide an area for office work	y	y
Pencils	writing	writing	y	y
Cameras	to take pictures	to take pictures	y	y
Chairs	to sit	to sit	y	y
Weights	lifting weights	lifting weights	y	y
Flashlights	to light dark areas	to light dark areas	y	y
Mops	cleaning	cleaning	y	y
Offices	workspace	workspace	y	y
Pencils	to write	to write	y	y
Cameras	take photos	take photos	y	y
Chairs	sitting	sitting	y	n
Weights	strength training	strength training	y	y
Flashlights	provide light	provide light	y	y
Mops	mop floors	mop floors	y	y
Offices	storage	store books	y	y
Pencils	writing	writing	y	y

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	2	2	-2	2	1	1	-2	2	0	-1	-1
Chairs	1	2	-1	2	1	-1	-1	0	2	-2	-2
Weights	2	2	0	-2	0	-1	1	0	1	0	0
Flashlights	0	empty	-1	0	0	0	0	1	1	1	0
Mops	0	0	0	0	0	0	0	0	0	0	1
Offices	0	0	0	2	0	0	0	0	2	2	0
Pencils	2	1	-1	0	0	1	0	0	1	1	0
Cameras	2	2	2	2	2	2	-2	2	2	-2	0
Chairs	2	2	0	1	1	0	0	2	0	-2	-2
Weights	1	2	-1	-2	0	-1	2	0	2	-2	2
Flashlights	-2	2	2	2	1	2	0	2	1	1	2
Mops	-2	2	-1	0	-1	-1	2	-1	1	0	0
Offices	0	0	-2	0	-1	-2	2	1	1	1	-1
Pencils	2	1	-1	1	0	1	0	0	0	-1	-1
Cameras	2	2	1	2	2	1	-2	2	1	-2	-1
Chairs	2	1	-1	1	2	-1	-1	1	2	-1	-1
Weights	1	2	-2	0	0	-2	-1	0	2	-2	-1
Flashlights	1	1	0	1	1	0	-1	1	1	-1	-1
Mops	1	2	-2	-1	-1	-1	1	-1	0	-2	-2
Offices	0	1	-1	1	0	-1	0	1	1	0	0
Pencils	2	2	0	0	1	1	0	0	1	0	0
Cameras	1	1	-1	-1	0	0	-2	2	2	-1	-1
Chairs	1	2	-1	1	0	-1	-1	1	1	-2	-1
Weights	1	1	-1	0	0	0	-1	0	1	-1	-1
Flashlights	2	2	0	-1	1	0	0	2	1	-1	-1
Mops	1	0	-2	-1	-1	-1	0	-2	0	-1	0
Offices	-1	0	0	-1	0	0	0	-1	1	0	0
Pencils	2	2	-1	1	1	1	0	0	1	-2	0

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	1	0	1	2	0	0	-2	1	-1	-1	-1
Chairs	1	2	-1	1	0	0	-1	2	1	-1	0
Weights	1	2	0	-1	0	-1	0	0	1	0	0
Flashlights	1	1	-1	1	1	1	-2	1	-1	0	0
Mops	1	1	-1	-1	0	-1	2	0	1	0	0
Offices	0	1	0	1	0	0	1	0	1	0	0
Pencils	2	1	-1	-1	0	1	0	1	1	-1	0
Cameras	0	1	1	2	0	0	-2	2	2	1	-1
Chairs	1	2	0	2	0	0	-1	0	1	-2	-1
Weights	-2	-2	0	-1	0	0	0	0	2	1	0
Flashlights	0	0	0	2	1	0	-1	1	1	0	-1
Mops	0	0	-1	1	-2	0	1	0	-1	1	1
Offices	0	0	0	1	0	0	1	0	2	0	0
Pencils	1	2	1	1	1	1	0	0	2	0	0
Cameras	-1	2	1	2	1	0	-2	1	1	-1	-2
Chairs	2	2	-1	1	0	0	1	0	2	-1	0
Weights	1	2	-1	0	0	-1	1	0	2	-2	-1
Flashlights	0	0	-1	1	0	1	0	0	-1	0	0
Mops	0	2	-1	0	-1	0	2	-1	1	1	0
Offices	0	2	1	1	0	-1	2	0	1	0	-1
Pencils	2	2	1	0	0	2	-1	0	0	-1	0
Cameras	2	2	-1	-2	0	0	-2	2	2	-1	-1
Chairs	1	1	0	0	0	0	2	1	2	-2	-1
Weights	1	0	-1	-2	0	-2	0	1	0	0	0
Flashlights	1	2	0	-1	1	2	-1	0	1	-1	0
Mops	0	0	0	-1	0	-1	0	-1	2	0	0
Offices	2	2	1	2	0	2	0	0	1	1	-1
Pencils	1	1	-2	0	2	0	0	0	0	-2	0

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	2	2	-1	2	0	0	-2	2	2	0	-2
Chairs	2	1	0	-1	2	0	0	2	2	-2	-2
Weights	1	2	-2	0	0	-1	1	-2	2	-2	-2
Flashlights	0	1	0	1	0	0	0	0	0	1	-1
Mops	0	1	0	0	0	0	0	0	1	2	2
Offices	0	1	-1	0	empty	-2	empty	empty	1	0	-1
Pencils	2	2	-1	0	0	1	0	1	0	-1	-1
Cameras	2	0	-1	2	1	2	-2	2	-2	-1	-2
Chairs	1	2	2	2	2	2	2	2	2	-2	-2
Weights	2	2	-2	2	0	-2	-1	2	2	-2	-2
Flashlights	0	empty	-2	1	-2	-2	0	-1	-1	-1	1
Mops	-1	0	-2	0	-2	-2	2	-2	2	1	1
Offices	2	1	-2	2	0	-2	2	0	2	2	0
Pencils	2	2	2	0	2	2	0	2	-1	2	-2
Cameras	2	0	2	1	1	0	-1	2	1	-1	-2
Chairs	1	1	2	1	0	2	2	2	1	-1	0
Weights	1	2	-1	0	1	0	1	0	0	0	1
Flashlights	1	0	1	0	1	1	-1	1	0	-1	0
Mops	1	0	0	0	1	1	2	0	2	1	0
Offices	-2	0	-2	0	0	-1	0	-1	1	1	0
Pencils	1	1	0	0	0	2	0	0	1	1	0
Cameras	2	2	-1	-2	0	1	-2	2	-1	-2	-2
Chairs	2	2	-1	2	2	-1	1	2	2	-2	-2
Weights	2	2	-2	2	1	-2	2	2	2	-2	-2
Flashlights	1	2	-1	-1	0	-1	-1	1	2	-1	-1
Mops	2	2	-2	-1	-2	-2	2	-2	2	-2	-2
Offices	0	2	-2	2	-1	-2	2	0	2	2	-2
Pencils	2	2	-2	-2	-1	-2	0	1	0	-2	0

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	2	2	-1	2	2	0	-2	2	2	-2	-2
Chairs	2	0	2	1	2	1	0	2	2	-2	-1
Weights	1	2	0	0	0	0	0	0	2	-1	-1
Flashlights	1	1	1	0	0	2	0	0	1	-1	0
Mops	0	0	-1	0	0	-1	2	-1	0	1	0
Offices	0	2	-1	1	0	-1	2	0	2	1	0
Pencils	2	2	2	0	2	2	0	0	0	-1	-1
Cameras	2	-2	0	1	2	2	-2	2	2	-1	-2
Chairs	-2	0	0	1	1	-1	-1	2	1	-2	-1
Weights	1	0	-1	0	0	-1	1	0	2	-1	-1
Flashlights	1	-2	2	-1	1	1	0	2	2	-1	-1
Mops	1	1	-1	0	0	-1	2	-1	0	-1	0
Offices	0	1	0	-1	0	0	1	0	1	0	0
Pencils	2	0	-1	0	-1	1	0	0	0	-1	-1
Cameras	2	2	0	2	0	0	-2	2	2	-2	0
Chairs	2	2	0	2	0	0	-2	2	0	-2	-2
Weights	2	2	0	0	0	0	0	0	2	0	-1
Flashlights	1	2	-1	2	0	0	-2	2	0	0	0
Mops	1	0	0	0	0	-1	2	-1	2	0	-1
Offices	1	0	-1	1	0	-1	0	0	2	1	-1
Pencils	2	2	-1	0	0	1	0	0	0	-2	-1
Cameras	0	1	0	2	1	1	-2	2	2	0	-2
Chairs	2	2	1	1	2	0	-2	2	2	-2	0
Weights	2	2	0	1	0	0	2	0	2	2	-2
Flashlights	0	2	1	1	2	2	-1	2	0	1	-1
Mops	1	0	-2	-1	-2	-2	1	-2	1	0	1
Offices	0	0	-1	2	1	-1	2	0	2	2	0
Pencils	2	2	-1	0	2	1	0	2	1	2	2

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	2	2	2	2	2	2	-2	1	2	-1	-2
Chairs	1	2	0	-1	0	0	1	1	0	0	0
Weights	1	2	0	0	0	0	0	-1	2	-1	0
Flashlights	1	2	0	1	0	0	-1	1	1	-1	-1
Mops	1	0	-2	0	1	-1	1	0	2	1	0
Offices	-1	2	-2	2	1	-2	2	0	2	0	0
Pencils	2	2	2	0	2	2	0	2	1	0	0
Cameras	2	1	-1	-2	0	2	-2	2	2	0	-2
Chairs	2	2	2	2	2	2	2	2	2	2	-1
Weights	2	2	-1	0	0	-1	0	0	0	-1	-1
Flashlights	1	2	1	-2	1	0	-1	2	0	0	-2
Mops	1	1	-1	0	0	0	1	-1	0	0	0
Offices	-1	2	1	2	1	0	2	-1	2	1	1
Pencils	2	2	-1	0	0	2	0	0	0	-2	-1
Cameras	2	2	-2	-2	-2	-2	-2	2	2	-2	-2
Chairs	2	2	-2	2	2	-2	-2	2	2	-2	-2
Weights	2	2	-2	-2	0	-2	1	0	2	-2	-2
Flashlights	2	2	2	0	0	2	-1	0	2	1	0
Mops	0	0	0	0	0	0	2	0	2	0	-2
Offices	2	0	0	0	0	-1	0	0	0	0	0
Pencils	2	2	-1	0	0	2	0	0	2	1	0
Cameras	2	2	-1	2	0	0	-2	2	2	-1	-1
Chairs	2	2	-2	2	0	-2	-2	1	1	-2	-2
Weights	1	2	-2	1	0	-1	1	0	2	-2	-2
Flashlights	0	1	-1	1	0	0	-1	0	-1	0	0
Mops	1	2	-1	0	0	0	1	0	1	-1	-1
Offices	0	1	-1	1	0	-1	1	-1	1	0	0
Pencils	2	2	1	1	0	1	0	0	1	-1	-1

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	2	2	-1	-1	0	1	-2	2	-1	-1	-2
Chairs	2	2	-1	1	1	-2	-1	1	1	-2	0
Weights	2	2	-1	0	1	-1	2	0	2	-1	-1
Flashlights	1	2	1	1	1	2	-2	0	-1	1	-1
Mops	1	1	0	0	1	0	2	0	2	2	1
Offices	0	1	-1	2	0	-1	0	1	0	0	0
Pencils	2	2	-1	0	-1	-1	0	0	1	-1	-1
Cameras	2	0	0	1	0	1	-2	2	0	-2	-2
Chairs	2	-1	-2	1	1	-1	0	2	2	-2	-1
Weights	1	1	0	0	0	0	2	0	2	-1	0
Flashlights	1	0	1	0	2	2	1	1	1	0	0
Mops	1	2	-2	0	0	-1	2	0	1	0	0
Offices	1	1	-2	0	-1	-2	0	0	1	0	0
Pencils	2	2	0	0	0	1	0	0	0	0	-1
Cameras	2	2	0	1	2	2	-2	2	-2	0	-1
Chairs	1	1	0	1	1	-1	1	0	1	-1	0
Weights	1	2	-1	-1	0	0	1	0	1	0	0
Flashlights	1	1	0	1	0	0	-1	1	0	0	-1
Mops	0	0	0	-1	-1	0	1	0	1	0	0
Offices	0	0	0	1	1	0	0	-1	0	0	0
Pencils	2	2	-1	0	2	1	0	0	1	-1	0
Cameras	-2	2	2	2	2	2	-2	2	2	-1	-1
Chairs	2	1	0	0	0	0	2	2	1	-2	-2
Weights	2	2	-2	-2	-2	-2	1	-2	1	-2	-2
Flashlights	2	0	1	2	-1	1	2	2	0	1	1
Mops	2	0	-2	-2	-1	-2	2	-2	1	-2	0
Offices	-2	2	-2	1	0	-2	2	-2	2	2	0
Pencils	2	2	0	0	-2	2	0	0	0	-2	0

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	1	1	0	0	0	0	-1	0	2	0	0
Chairs	1	2	-1	2	0	-1	-2	0	0	-2	0
Weights	1	2	0	0	0	-1	1	0	1	0	0
Flashlights	0	0	0	0	0	0	0	0	0	0	0
Mops	0	0	0	-1	0	0	0	0	1	1	1
Offices	0	0	-1	1	0	-1	0	0	0	0	0
Pencils	1	2	-1	0	-1	-2	0	0	1	-1	-1
Cameras	2	2	0	2	1	0	-2	2	0	-2	-2
Chairs	2	2	0	2	1	0	-1	0	2	-2	-2
Weights	2	2	-2	-2	0	-1	0	0	2	-2	-2
Flashlights	0	2	0	1	0	0	-2	0	0	1	0
Mops	0	0	0	0	0	0	2	-1	0	0	0
Offices	0	0	1	2	0	1	0	1	1	2	0
Pencils	2	2	0	0	2	1	0	0	1	2	0
Cameras	1	2	-1	2	0	0	-2	2	1	-1	-1
Chairs	2	1	-1	0	0	0	-1	1	2	-2	0
Weights	2	2	0	0	0	0	1	1	2	-1	-1
Flashlights	2	2	-1	0	2	2	0	2	1	-2	0
Mops	-1	0	0	0	0	-1	0	-1	0	2	1
Offices	-1	0	-1	2	0	-1	1	0	1	1	0
Pencils	2	2	-1	0	0	1	0	0	0	-1	0
Cameras	2	2	-1	1	0	0	-2	1	0	-2	-2
Chairs	1	0	-2	0	1	-2	0	1	2	-2	0
Weights	1	2	-1	0	0	-1	0	0	2	-2	0
Flashlights	0	2	0	0	0	1	0	0	0	1	0
Mops	1	0	0	0	0	0	2	0	0	0	-1
Offices	0	1	0	2	0	-1	2	0	2	1	0
Pencils	2	2	-1	0	0	0	0	0	0	-1	0

Table 10 (continued)

Objects	Complex	Replaceable	Durable	Function	Performance	Long Lasting	Portable	Professional	Versatile	Easy Mx	Easy Use
Cameras	2	2	0	2	0	0	-2	2	1	0	-2
Chairs	2	2	-1	0	0	0	-1	1	2	0	0
Weights	2	2	-1	-1	1	-1	0	-1	2	-1	1
Flashlights	0	1	0	1	0	1	-1	1	0	-1	-1
Mops	0	2	-2	-1	-1	-1	2	-2	0	1	1
Offices	0	0	-1	0	0	0	0	0	0	1	0
Pencils	2	2	-2	0	0	1	0	1	0	2	0
Cameras	2	2	-1	-1	2	1	-2	2	-2	-2	-2
Chairs	2	2	-1	1	0	-1	-1	1	0	-2	-2
Weights	2	2	0	-2	0	-1	1	2	2	-2	-2
Flashlights	1	0	1	2	2	2	-1	2	0	-1	-2
Mops	1	0	-1	-2	-1	0	0	-1	1	1	1
Offices	-1	0	-2	2	-1	-2	2	0	1	-1	0
Pencils	2	1	-1	-2	-2	-2	0	0	0	-2	-2
Cameras	2	1	-1	2	1	0	-2	2	2	0	-1
Chairs	2	2	-1	-1	0	0	-1	1	2	0	0
Weights	2	2	-2	0	0	-1	1	-1	1	-1	-1
Flashlights	0	2	-1	0	0	1	-1	0	1	-1	-1
Mops	1	0	0	0	1	1	2	-1	1	1	0
Offices	1	1	-1	2	0	-1	2	0	1	0	0
Pencils	2	2	0	1	1	1	0	1	1	1	-1

E2. Product Graphs

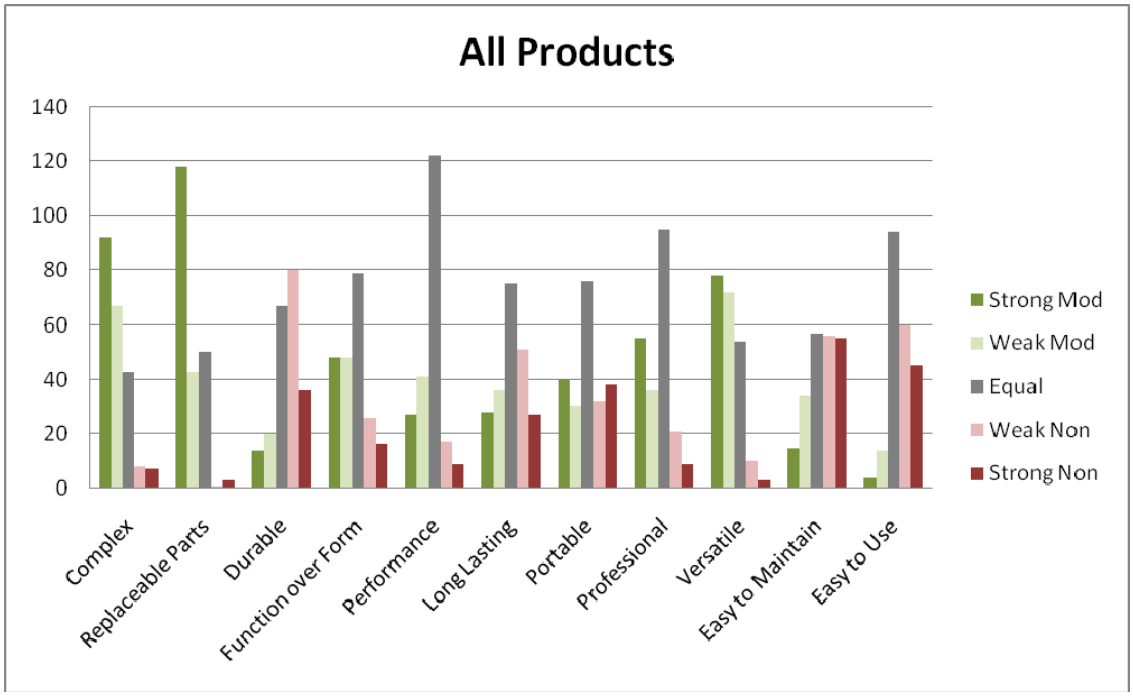


Figure 27. Product Trait Graph: All Products

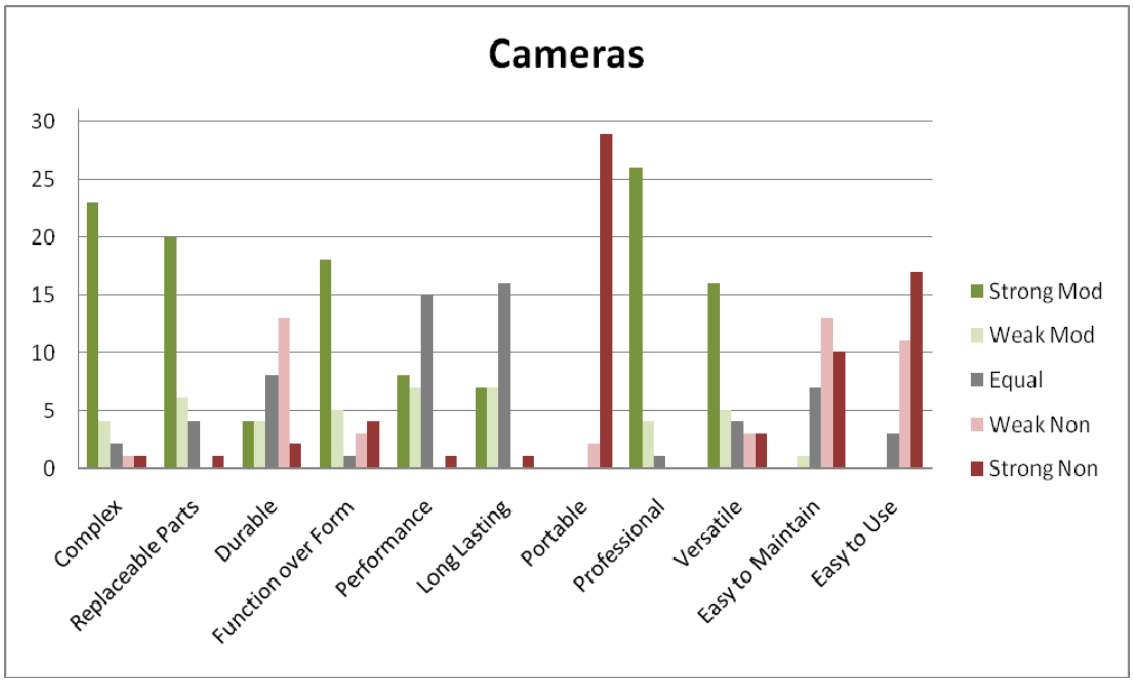


Figure 28. Product Trait Graph: Cameras

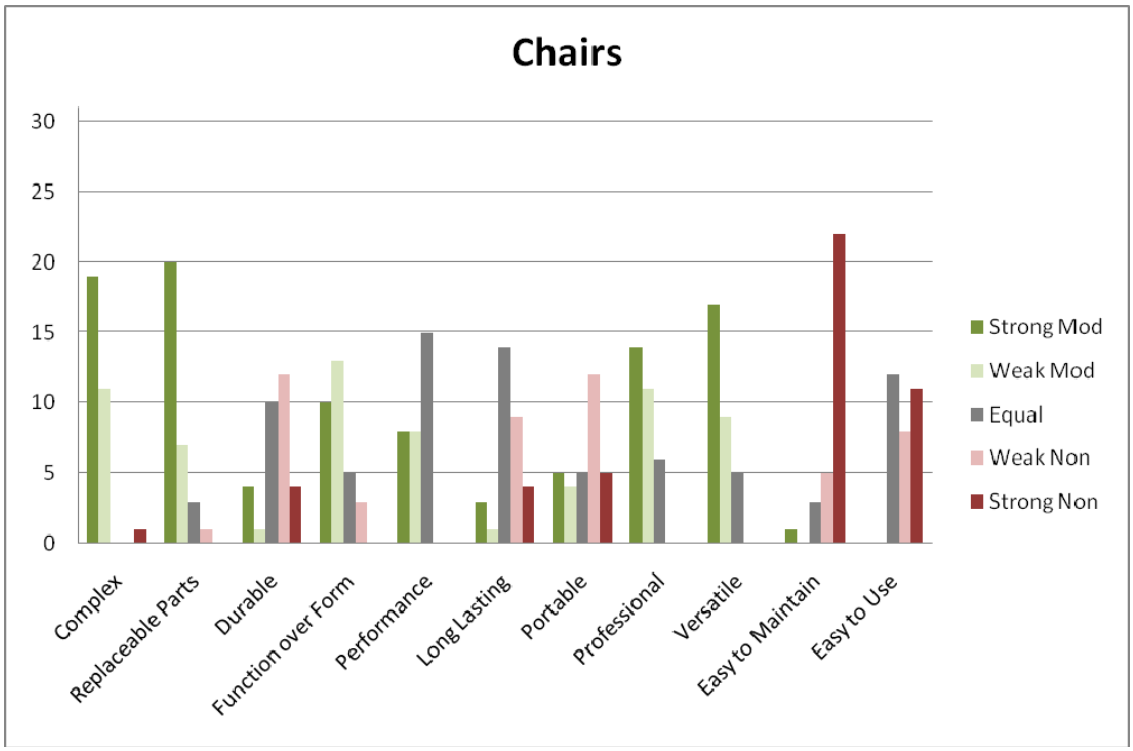


Figure 29. Product Trait Graph: Chairs

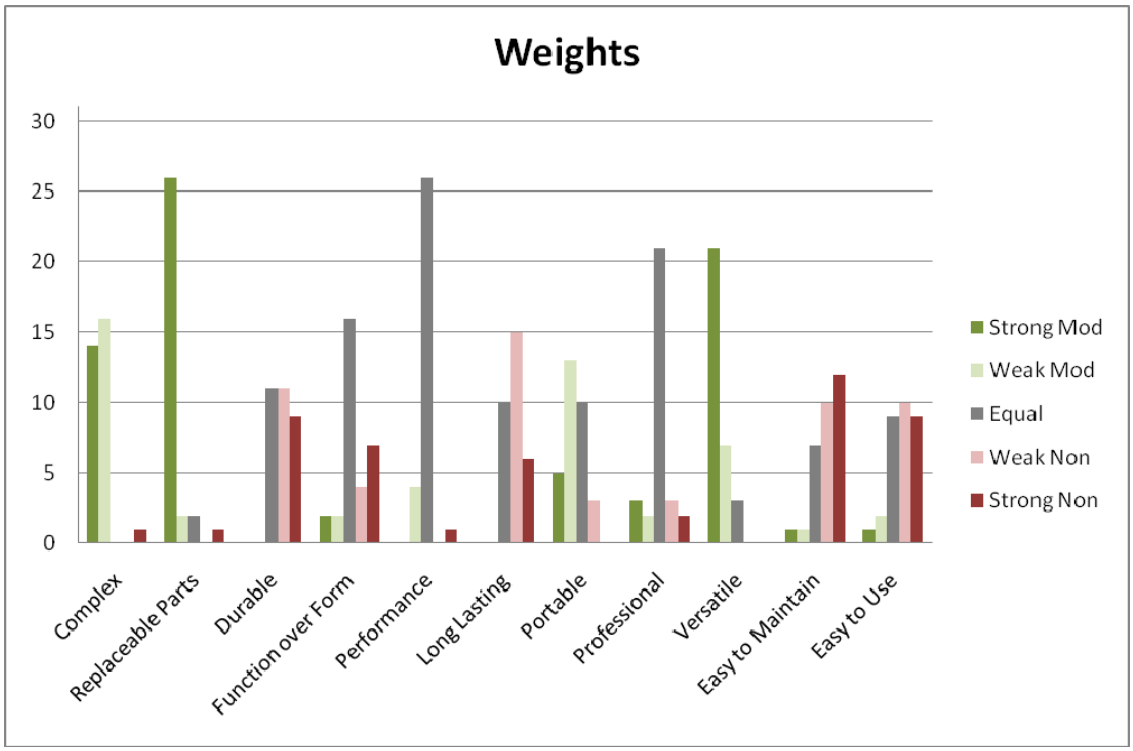


Figure 30. Product Trait Graph: Weights

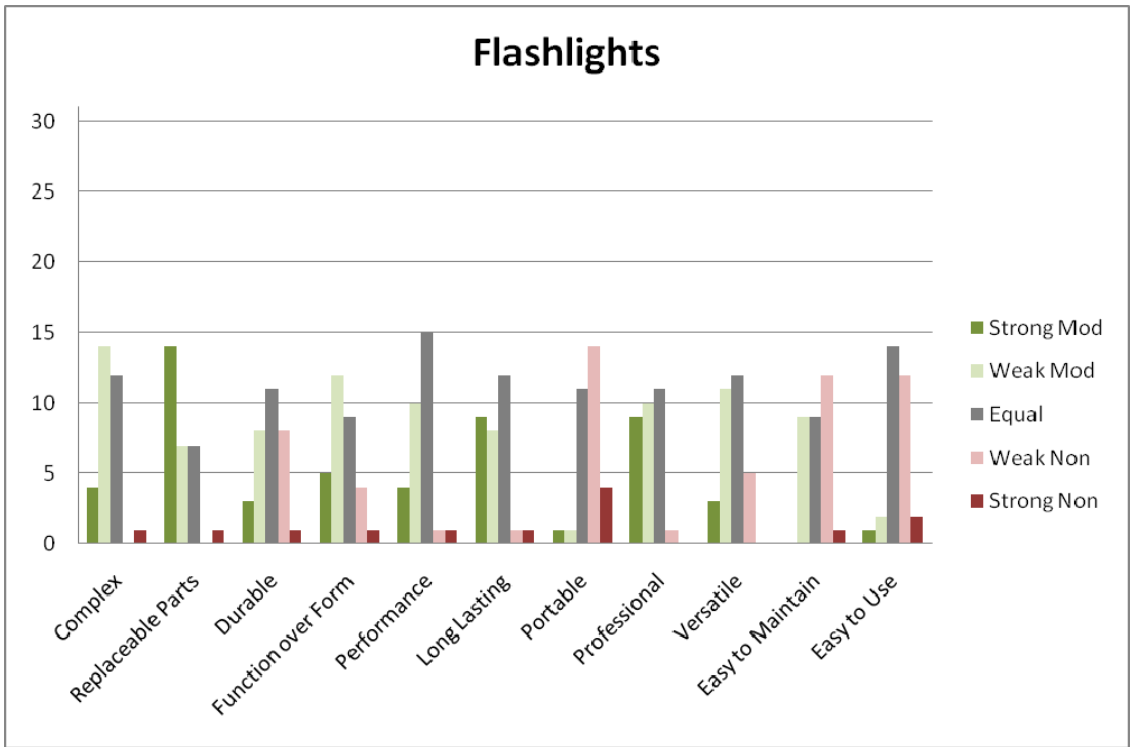


Figure 31. Product Trait Graph: Flashlights

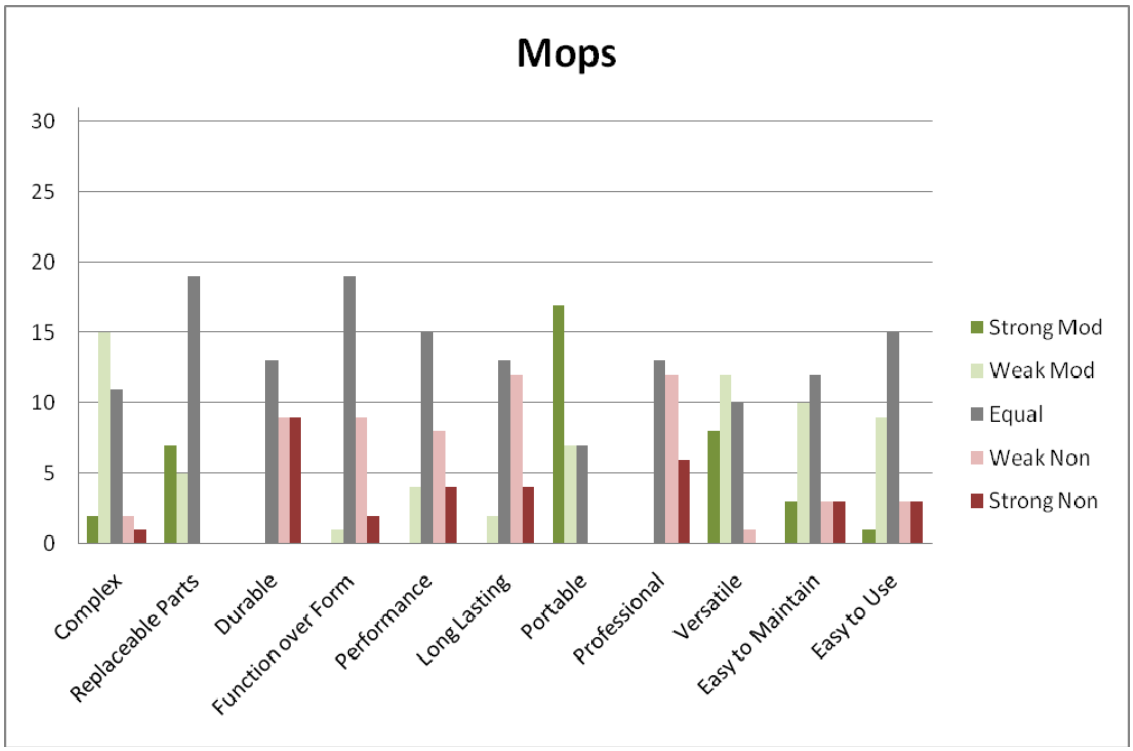


Figure 32. Product Trait Graph: Mops

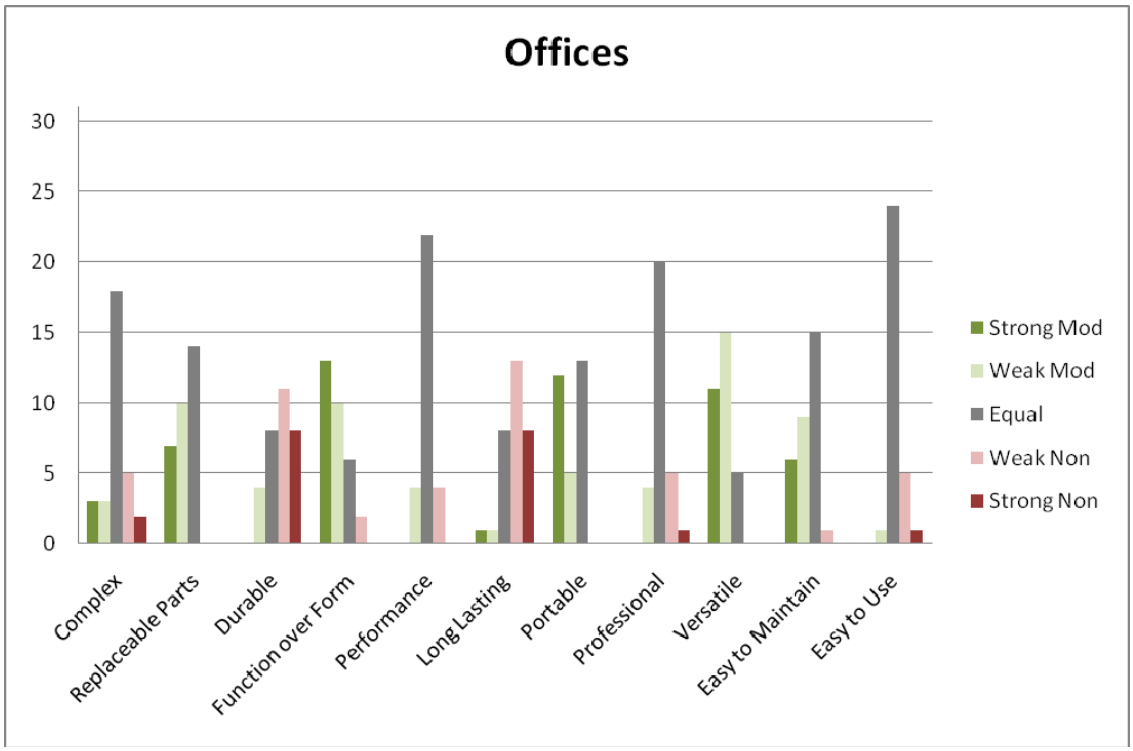


Figure 33. Product Trait Graph: Offices

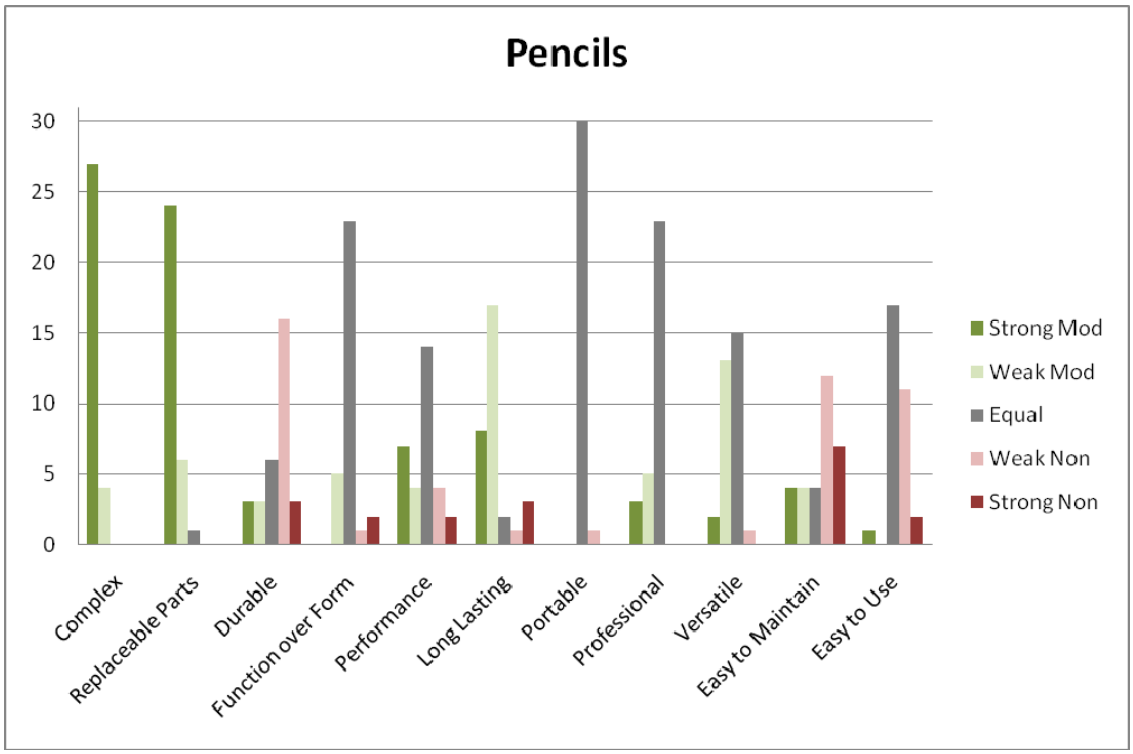


Figure 34. Product Trait Graph: Pencils

E3. Predefined Category Remaining Comparison Charts

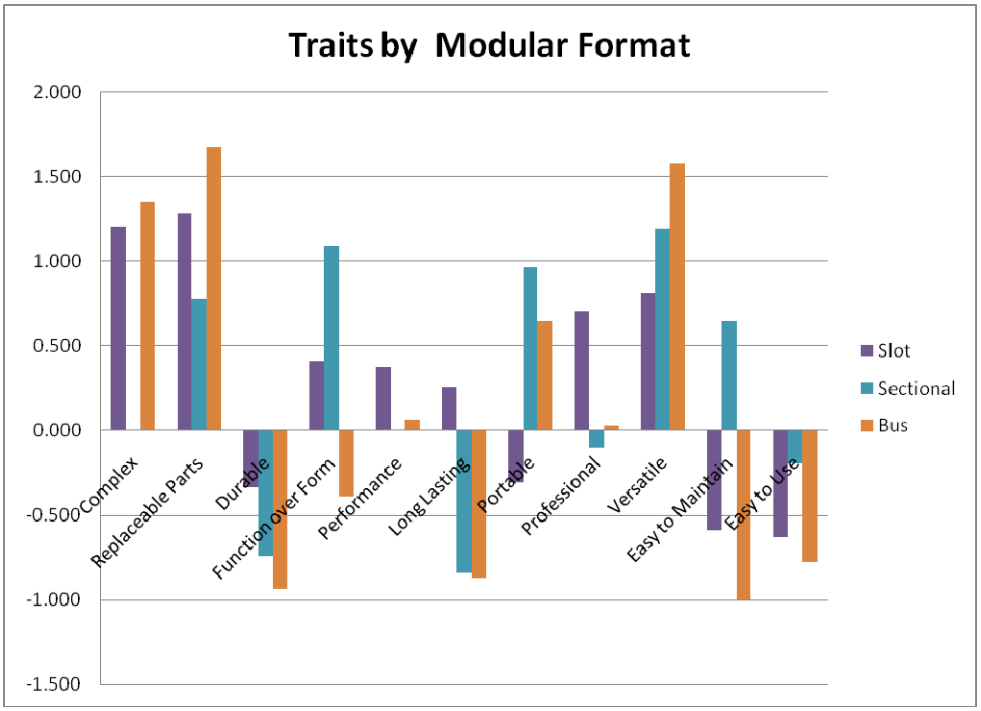


Figure 35. Predefined Categories: Traits by Format

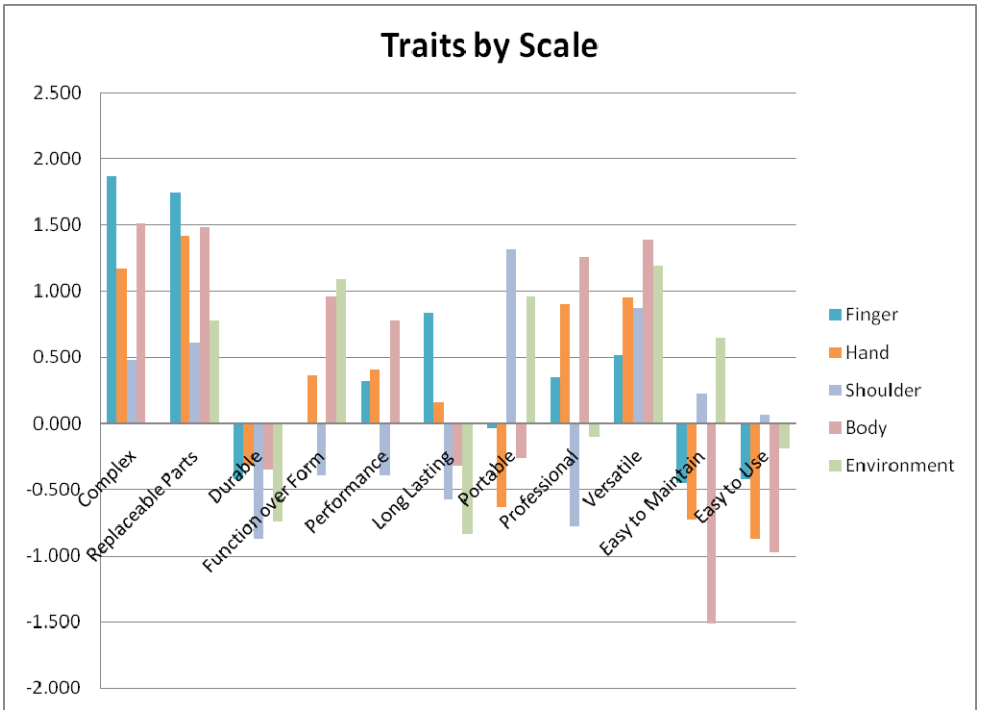


Figure 36. Predefined Categories: Traits by Scale

E4. Object Pair Similarity Measures

Table 11. Standard Deviations of Average Trait Scores Between Object Pairs

	Camera	Chair	Flashlight	Mops	Office	Pencil	Weights
Camera		0.689	0.772	1.666	1.489	0.932	1.258
Chair	0.689		0.773	1.278	1.117	0.758	0.755
Flashlight	0.772	0.773		1.080	0.957	0.564	1.004
Mops	1.666	1.278	1.080		0.602	1.000	0.775
Office	1.489	1.117	0.957	0.602		1.076	0.906
Pencil	0.932	0.758	0.564	1.000	1.076		0.762
Weights	1.258	0.755	1.004	0.775	0.906	0.762	

E5. Trait Comparison Scatter Plots

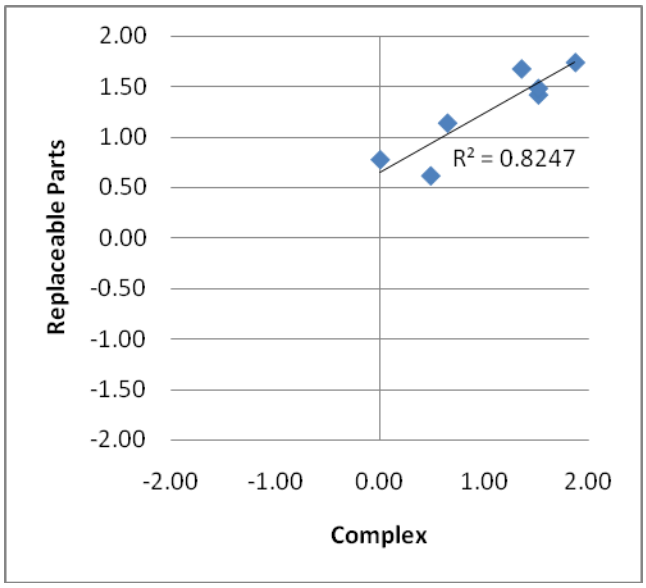


Figure 37. Trait Comparison: Comlex vs Replaceable

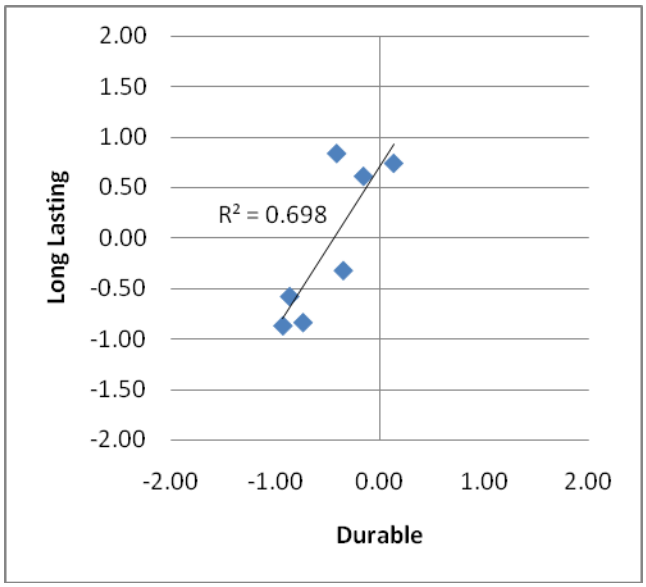


Figure 38. Trait Comparison: Durable vs Long Lasting

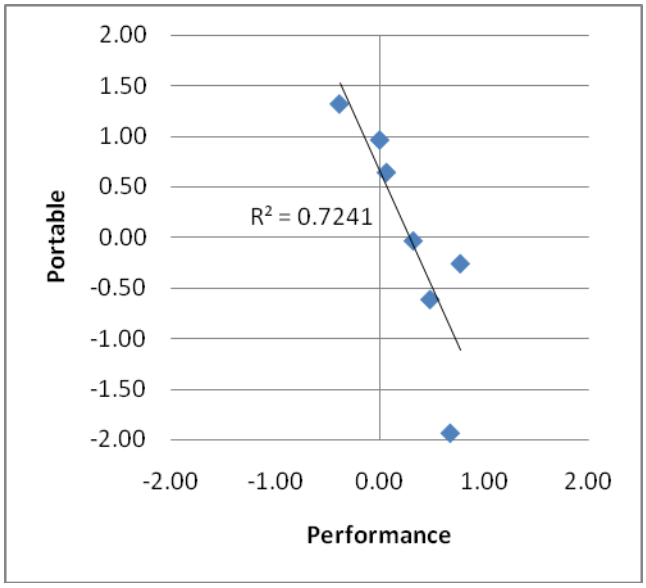


Figure 39. Trait Comparison: Performance vs Portable

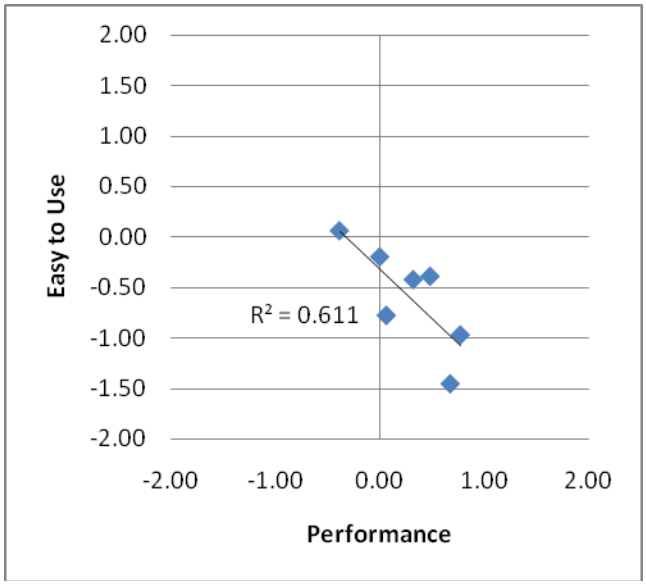


Figure 40. Trait Comparison: Performance vs Easy to Use

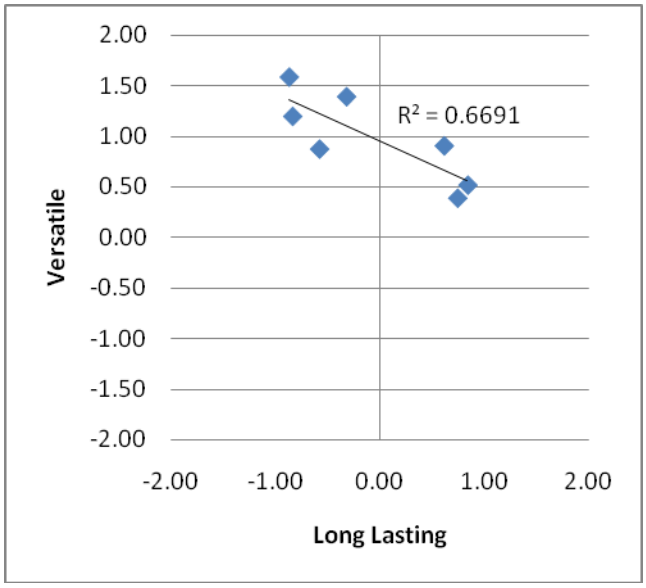


Figure 41. Trait Comparison: Long Lasting vs Versatile

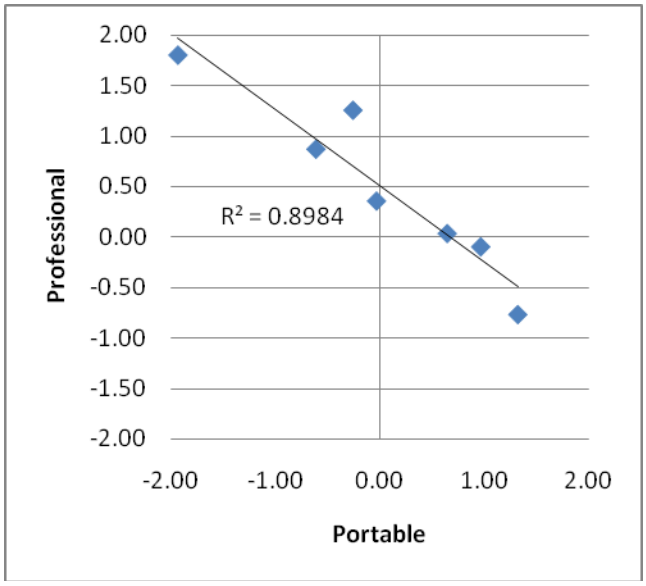


Figure 42. Trait Comparison: Portable vs Professional

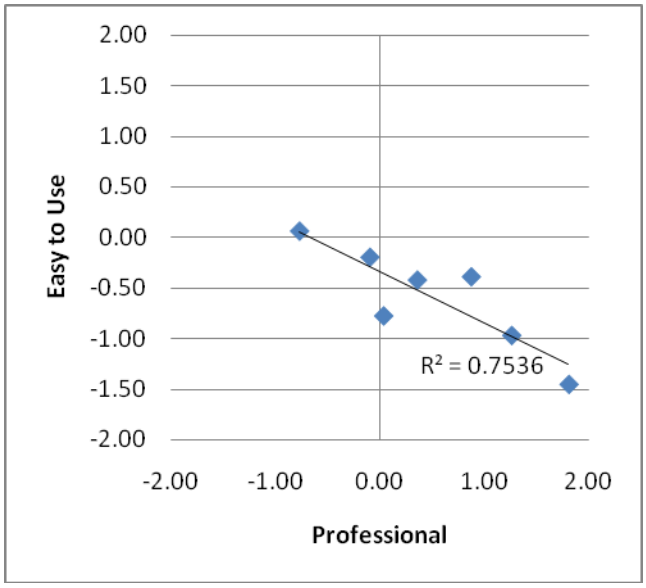


Figure 43. Trait Comparison: Professional vs Easy to Use

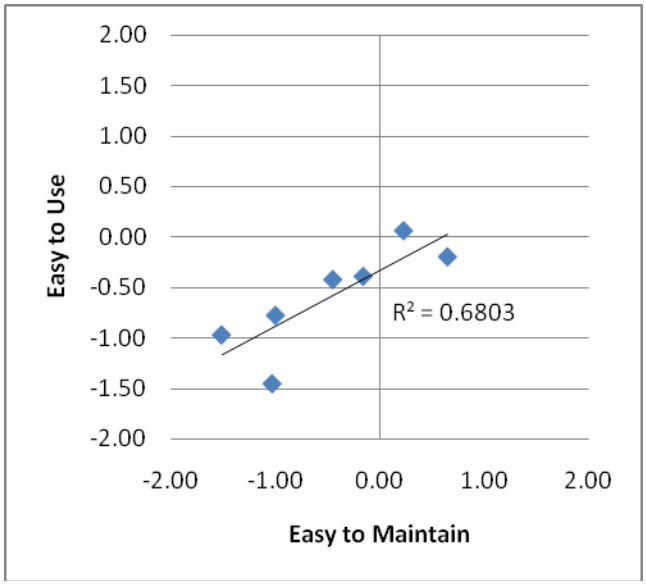


Figure 44. Trait Comparison: Easy to Maintain vs Easy to Use

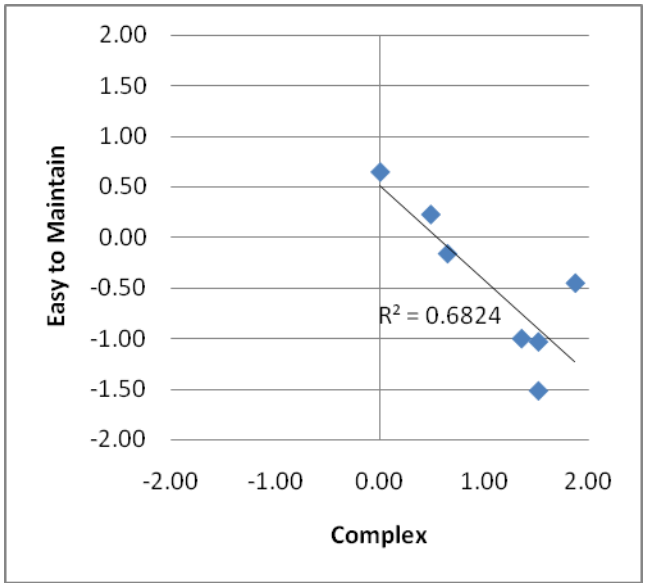


Figure 45. Trait Comparison: Complex vs Easy to Maintain

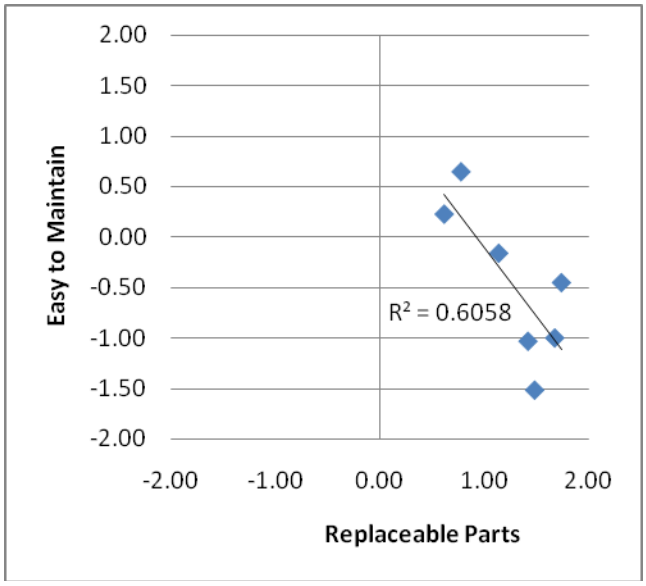


Figure 46. Trait Comparison: Replaceable Parts vs Easy to Maintain

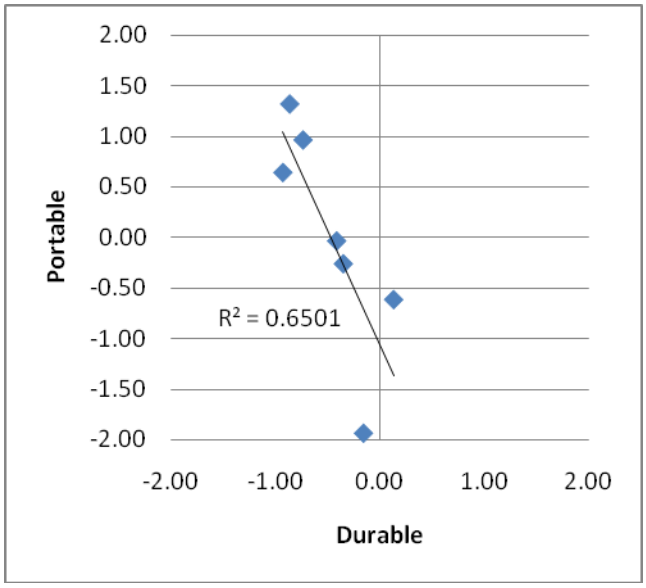


Figure 47. Trait Comparison: Durable vs Portable

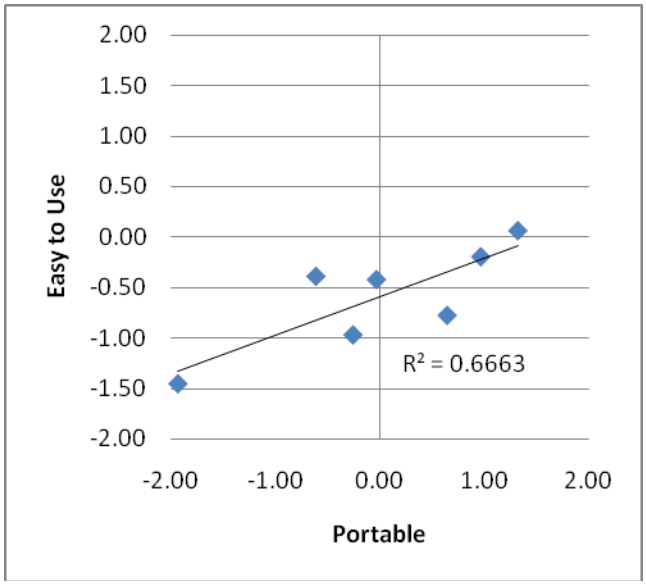


Figure 48. Trait Comparison: Portable vs Easy to Use

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